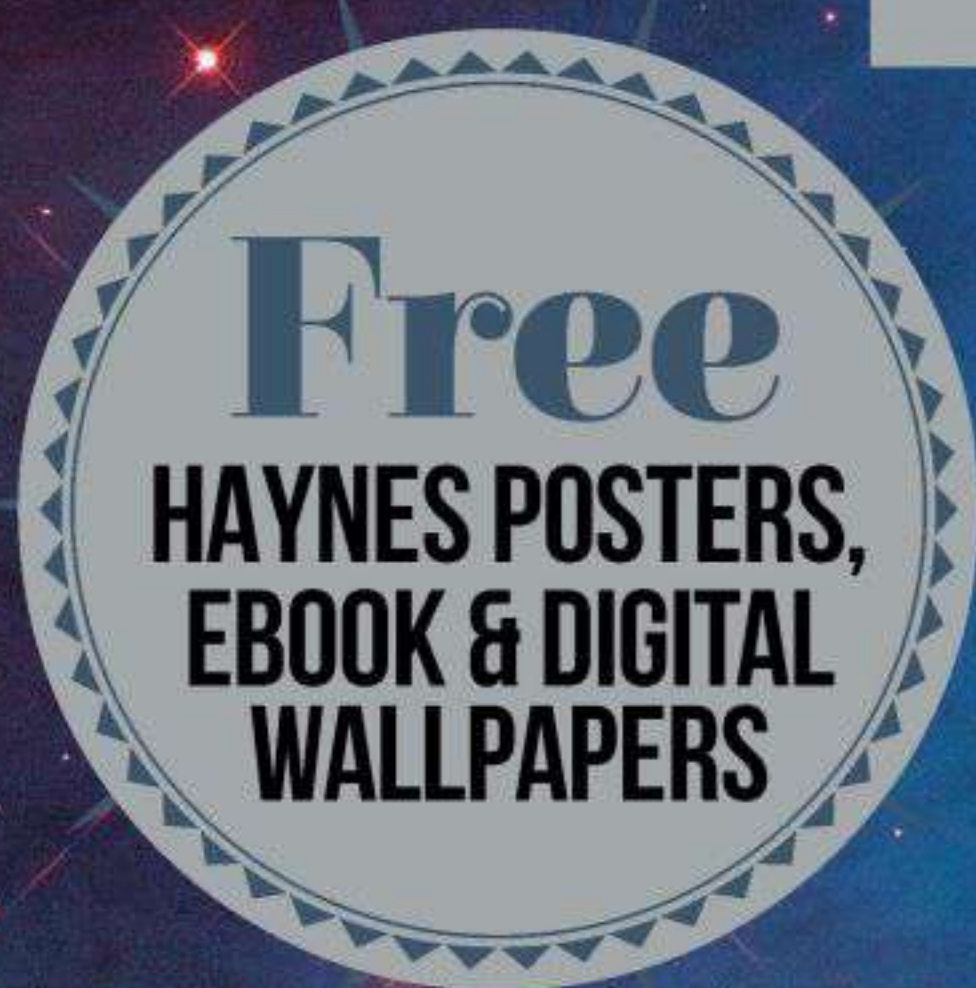


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Cover 1 of 30

All About Space



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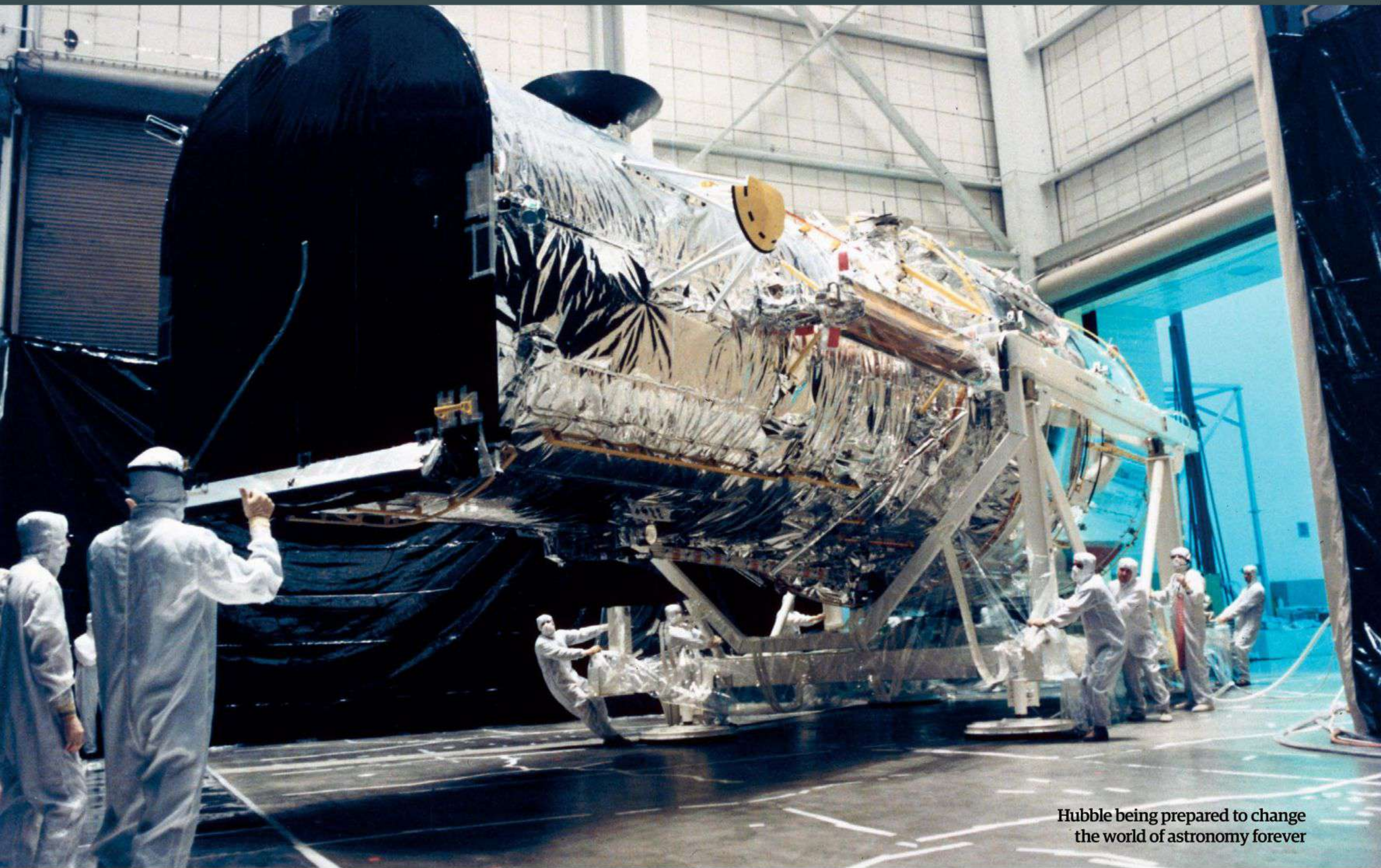
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Hubble being prepared to change
the world of astronomy forever



Welcome

Do you remember where you were and what you were doing when the

Hubble Space Telescope launched? After doing a quick survey around the office, not many can. However - quite unsurprisingly - what they do recall is the incredible set of discoveries, images and turning points that have not only made some corners of the universe much more visible, but brought us to the 30th anniversary of one of humankind's greatest achievements. It truly is a massive milestone - and we've made sure to celebrate it.

This month, whether you're a subscriber to the magazine or hunt for us in your local newsagent or supermarket, you'll be able to get hold of 30 exclusive **All About Space** covers, each featuring one

of Hubble's very best images. From Jupiter to the Helix Nebula to the famous Pillars of Creation, we're sure you'll find your favourite galaxy, nebula, star cluster or planet that has fallen into the crosshairs of the long-serving space telescope.

And that's not all - Hubble scientists past and present have weighed in with their favourite moments in the mission's history, while former NASA astronaut Mike Massimino reveals the time he broke the space telescope on a spacewalk. We've kept the celebration going with a free Hubble poster for all of our readers, digital wallpaper downloads and a free eBook to kick back with this spring. Enjoy!

Gemma Lavender
Editor-in-Chief

Our contributors include...



Jonathan O'Callaghan
Space science writer
Find out everything you need to know about the Space Force in Jonathan's report on page 52. Is it the answer to space warfare?



Jamie Carter
Astronomer
It's northern lights season, and seasoned aurora observer Jamie brings you the best tips and tricks to catch nature's amazing light show on page 76.



Neil deGrasse Tyson
Astrophysicist
Tyson exclusively reveals details of his up-and-coming show, *Cosmos: Possible Worlds*, with Ann Druyan in part one of our interview.



Colin Stuart
Space science writer
Do white dwarfs host alien life? Colin reveals why we should have been looking around them all along and how they provide a glimpse into our Sun's future.

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WEIRD BURSTS FROM OUTER SPACE





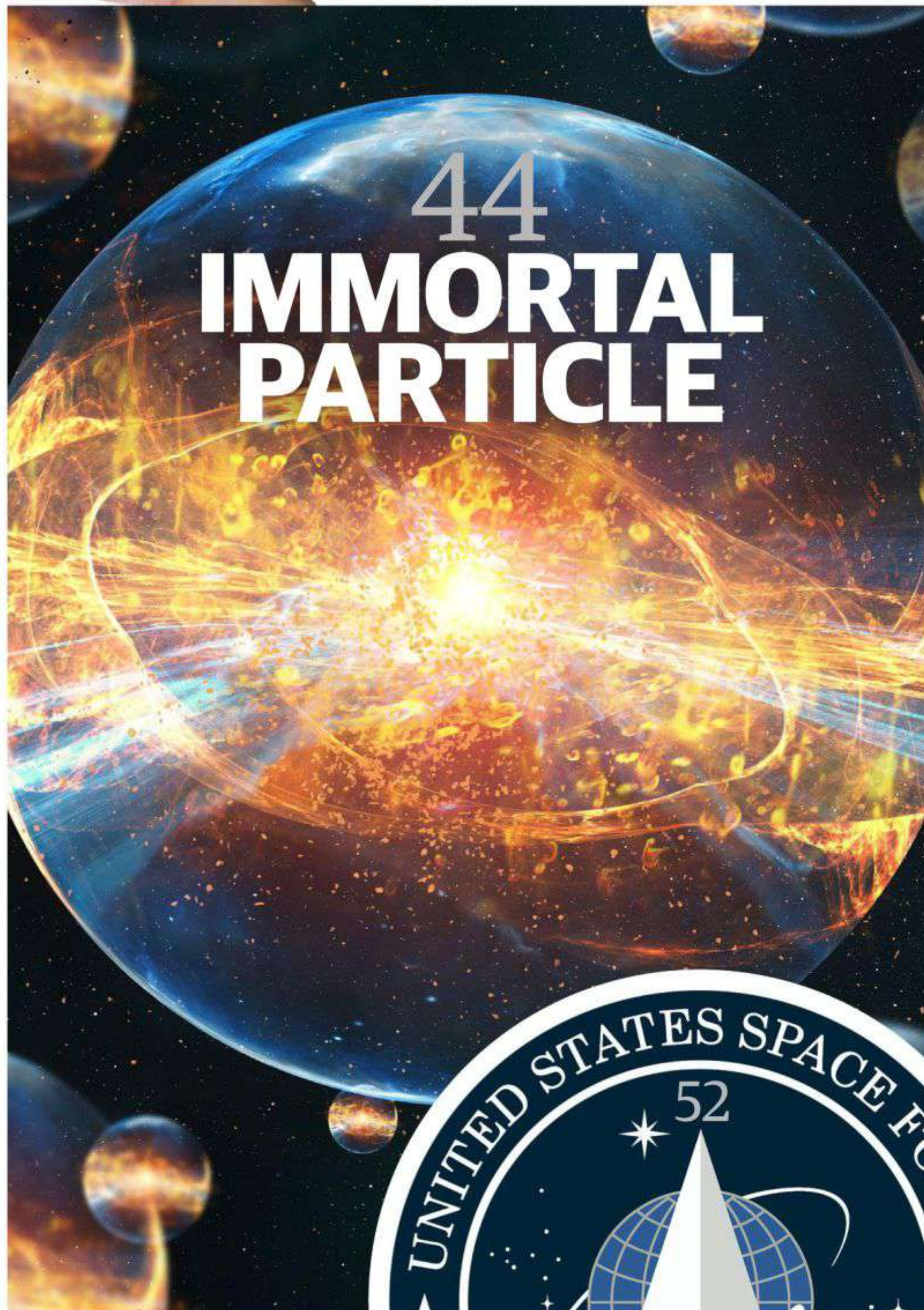
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Airglow lights up the Chilean desert

Airglow is a fantastic phenomenon that only graces a select number of regions across the entire world. The Atacama Desert in Chile is one of these locations, as it is as far from light pollution as possible and exhibits very few cloudy nights. It is this lack of artificial light and interference that brings a glow to the air. Within Earth's atmosphere, molecules are constantly colliding and emitting radiation over a range of wavelengths and colours. The mechanism is responsible for the majestic multicoloured sky over the dry Atacama Desert, visible in this image.



© NASA

The start of Expedition 62

At the International Space Station's changing of the guard, a new expedition dawns. Expedition 62 is now the focus of attention: the mission patch for the venture is pictured in front of the seven-windowed Cupola module, nicknamed the 'window to the world'.

As the space station orbits Earth every 90 minutes, six astronauts get to work conducting vital repairs, scientific studies and generally just enjoy life in microgravity. However, there comes a time when three astronauts leave and three new ones arrive, and this signifies the start of a new 'era' for the International Space Station.

Space station photobomb

The last two years of preparation for amateur astrophotographer Javier Manteca resulted in this spectacular shot of a waxing gibbous Moon with a streaking photobomb by the International Space Station. This fantastic image is a culmination of 17 stacked frames, taken in the small town of Campo Real in Madrid, Spain. On the same night that Manteca was preparing for this shot, European Space Agency astronaut Luca Parmitano handed over the command of the Earth-orbiting outpost to Russian cosmonaut Oleg Skripochka prior to his departure, returning to Earth the following day.



© Javier Manteca

European satellites capture an iceberg shattering

The Pine Island Glacier is located in western Antarctica and is one of the world's fastest-changing ice streams, responsible for a quarter of the continent's ice loss. In this cloud-free picture of the glacier, the European Space Agency's Copernicus Sentinel-2 captured the breaking and shattering of an iceberg 300 square kilometres (116 square miles) in size.

Earth Observation missions such as Copernicus are key to understanding large-scale changes that are happening on Earth. In fact, growing cracks in the Pine Island Glacier were first spotted by the mission last year. Since then, scientists have carefully monitored the situation to track how fast the cracks are growing.







Hubble versus Herschel

As the Hubble Space Telescope rapidly approaches the 30th anniversary of its launch, it continues to flaunt a illustrious catalogue of deep-space spectacles. This snapshot of the spiral galaxy NGC 691, located 120 million light years from Earth, distinctly shows its galactic arms spanning outwards, with dust trails springing into view as you look closer at the galactic core. This galaxy was discovered by astronomer William Herschel, who spent decades identifying and characterising galaxies to build a catalogue, some 200 years before the long-serving telescope blasted off into space.

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would
unlock more
mysteries

Ripples in space-time could explain the mystery of why the universe exists

Words by Yasemin Saplakoglu

New research may help answer one of the universe's biggest mysteries: why is there more matter than antimatter? That answer in turn could explain why everything from atoms to black holes exist.

Billions of years ago, almost immediately after the Big Bang, cosmic inflation stretched the tiny seed of our universe and transformed energy into matter. Physicists think inflation initially created the same amount of matter and antimatter, which annihilate each other on contact. But then something happened that tipped the scales in favour of matter, allowing everything we can see and touch to come into existence - a new study suggests that the explanation is hidden in very slight ripples in space-time.

"If you just start off with an equal component of matter and antimatter, you would just end up with having nothing" because antimatter and matter have equal but opposite charge, said Jeff Dror, a postdoctoral researcher at the University

of California, Berkeley, and physics researcher at Lawrence Berkeley National Laboratory. "Everything would just annihilate."

Obviously everything did not annihilate, but researchers are unsure why. The answer might involve very strange elementary particles known as neutrinos, which don't have electrical charge and can thus act as either matter or antimatter.

One idea is that about a million years after the Big Bang, the universe cooled and underwent a phase transition, an event similar to how boiling water turns from a liquid into a gas. This phase change prompted decaying neutrinos to create more matter than antimatter by some "small, small amount," Dror explained. But "there are no very simple ways - or almost any ways - to probe [this theory] and understand if it actually occurred in the early universe".

But Dror and his team, through theoretical models and calculations, figured out a way we might be able to see this phase transition. They

proposed that the change would have created extremely long and extremely thin threads of energy called 'cosmic strings' that still pervade the universe. Dror and his team realised that these cosmic strings would most likely create very slight ripples in space-time called gravitational waves. Detect these gravitational waves, and we can discover whether this theory is true.

The strongest gravitational waves in our universe occur when a supernova - or dying star explosion - happens, when two large stars orbit each other or when two black holes merge. But the proposed gravitational waves caused by cosmic strings would be much tinier than the ones our instruments have detected before.

"If these strings are produced at sufficiently high energy scales, they will indeed produce gravitational waves that can be detected by planned observatories," Tanmay Vachaspati, a theoretical physicist at Arizona State University who wasn't part of the research, said.

The early Earth had water, but no continents

Words by Mindy Weisberger

What did Earth look like 3.2 billion years ago? New evidence suggests the planet was covered by a vast ocean and had no continents. These appeared later as plate tectonics thrust enormous, rocky land masses upward to breach the sea surface. Scientists found clues about this ancient water world preserved in a chunk of ancient seafloor, now located in the outback of northwestern Australia.

Around 4.5 billion years ago, high-speed collisions between dust and space rocks formed the beginnings of our planet: a bubbling, molten sphere of magma that was thousands of miles deep. Earth then cooled as it spun; eventually, after 1,000 to 1 million years, the cooling magma formed the first mineral crystals in Earth's crust.

Earth's first water may have been carried here by ice-rich comets from outside our Solar System, or it may have arrived in dust from the cloud of particles that birthed the Sun and its orbiting planets, around the time of Earth's formation.

When the early Earth was still a hot magma ocean, water vapour and gasses escaped into

Right: Plate tectonics formed our continents, changing Earth forever

the atmosphere. "It then rained out from the atmosphere as conditions got cool enough," said Benjamin Johnson, an assistant professor in the Department of Geological and Atmospheric Sciences at Iowa State University. "We can't really say what the source of the water is from our work, but we do suggest that whatever the source, it was present when the magma ocean was still around," Johnson explained.



Oddball giant white dwarf may have formed in crash between smaller stars

Words by Charles Q. Choi

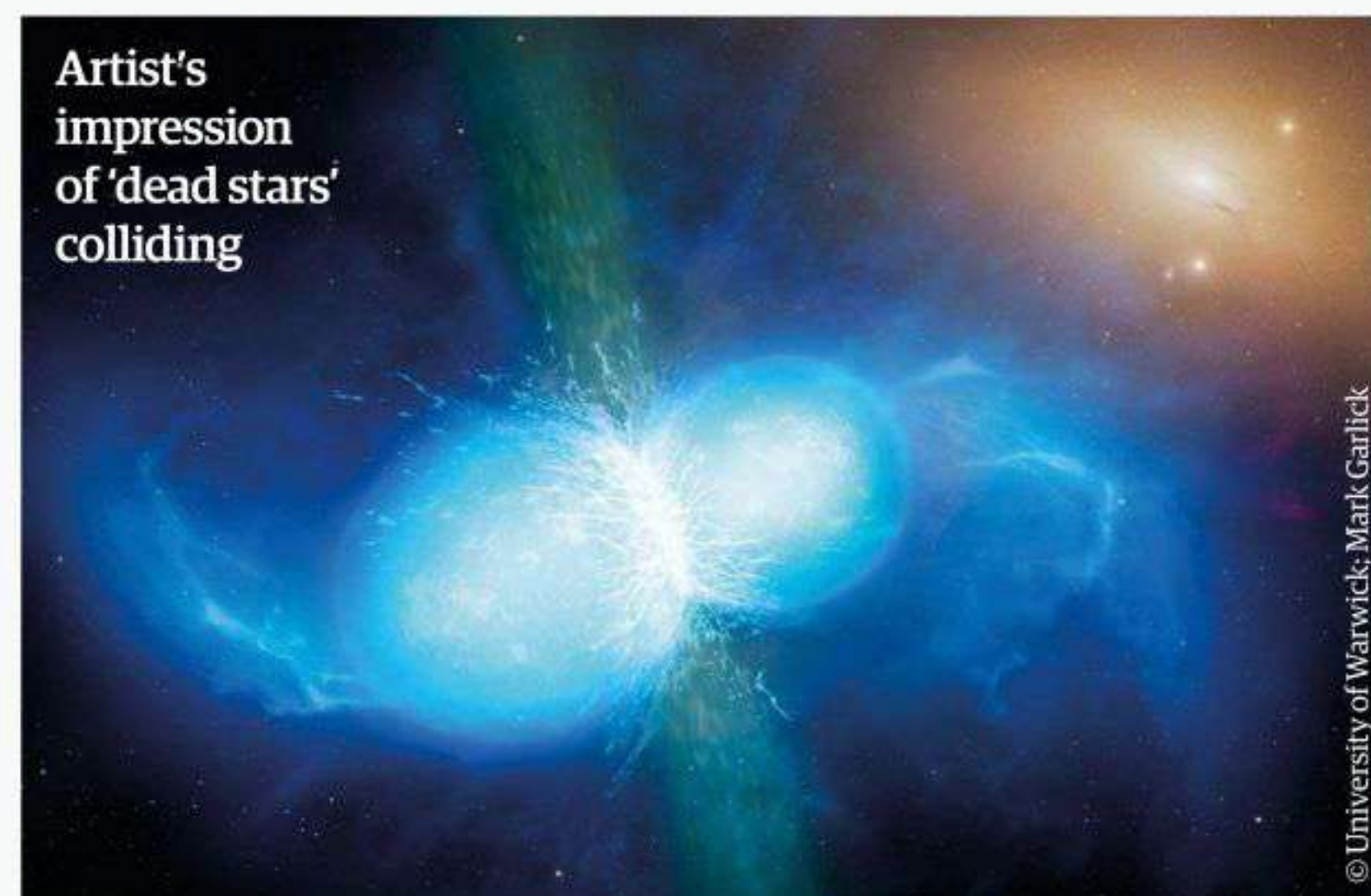
A giant white dwarf star may be the offspring of a collision between two other white dwarfs, which may help shed light on how massive these stars must be in order to explode in a supernova. White dwarfs are the dim, fading cores of dead stars that are left behind after average-size stars have exhausted their fuel and shed their outer layers. Our Sun will one day become a white dwarf, as will more than 90 per cent of the stars in our galaxy.

Scientists led by Mark Hollands, an astrophysicist at the University of Warwick, England, studied a white dwarf known as WDJ0551+4135, which is located about 150 light years from Earth. The European Space Agency's Gaia telescope suggested that this object might be an exceptionally massive white dwarf. To learn more about this unusual dead star, the scientists analysed it using data from the William Herschel Telescope in the Canary Islands.

By examining the spectrum of colours in light emitted by the white dwarf, the team were able to identify the chemicals within the star. Unexpectedly, the researchers found a high level of carbon in the object's atmosphere, which scientists had never seen before in white dwarfs. For the researchers, a key clue to this mystery was in the mass. Most white dwarfs are about 0.6 times the

'weight' of the Sun, but WDJ0551+4135 is nearly twice the average mass of a white dwarf at 1.14 solar masses, all compacted into a space just two-thirds of Earth's diameter.

Another clue is this white dwarf's apparent age. Older white dwarfs typically are cooler and orbit the centre of the Milky Way faster than their younger counterparts, because they have lost more heat over time and have experienced more gravitational interactions with other stars that speed them up. However, WDJ0551+4135 moves faster than 99 per cent of other nearby white dwarfs that have about the same temperature.

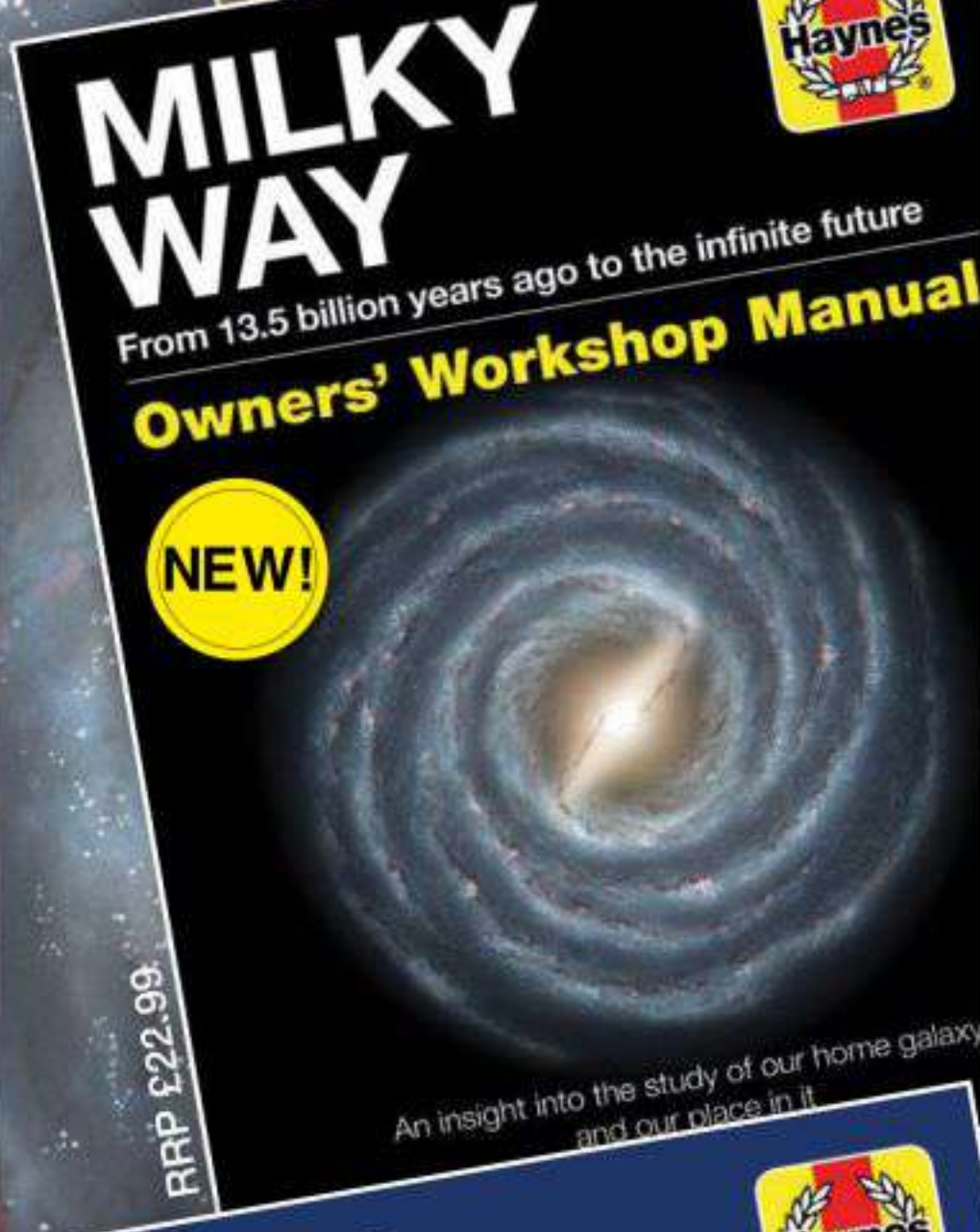




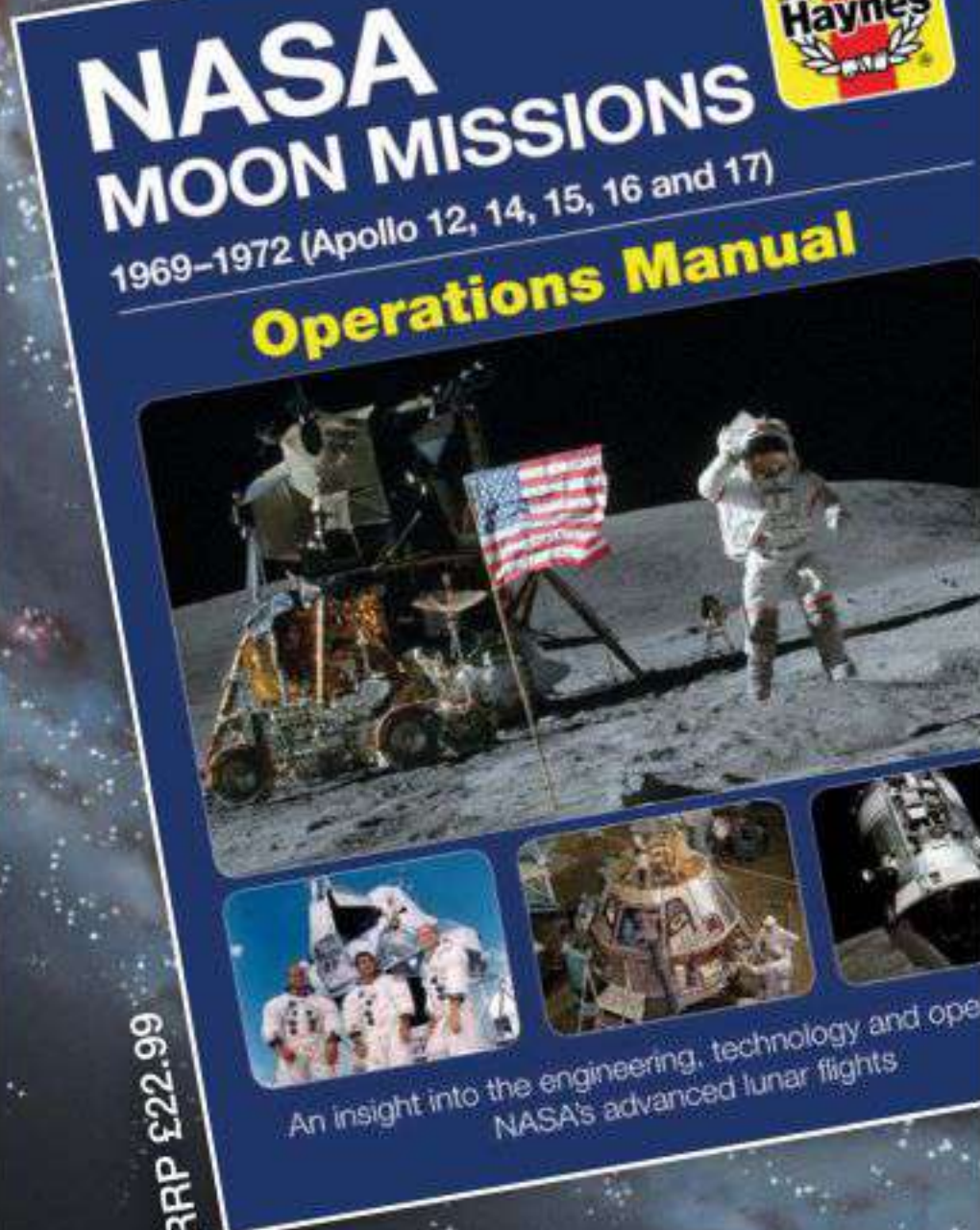
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SpaceX moving on to second Starship after first bites the dust

Words by Mike Wall

Elon Musk seems to be taking SpaceX's recent Starship setback in stride. In late February the second full-size prototype of SpaceX's Mars-colonising Starship vehicle, a variant known as the SN1, was destroyed during a pressurisation test.

SpaceX had been aiming to launch the SN1 on a test mission relatively soon.

Musk didn't immediately tweet about Friday night's incident, but the entrepreneur posted a few items on 2 March that suggest he's not dwelling on SN1's demise.

"So... how was your night?" read one tweet, which accompanied a video of the prototype's death. This was followed by "It's fine, we'll just buff it out," and then another tweet that said, "Where's Flextape when you need it!?"

In another tweet, Musk said that SpaceX has shifted its focus to the next prototype, SN2, which is already under construction.



© SpaceX

Above: The explosion occurred in the Ophiuchus Supercluster

Universe's biggest known explosion has been spotted

Words by Mike Wall

A gargantuan explosion tore through the heart of a distant galaxy cluster, releasing about five-times more energy than the previous record holder, a new study reports. "In some ways this blast is similar to how the eruption of Mount St Helens in 1980 ripped off the top of the mountain," Simona Giacintucci of the Naval Research Laboratory in Washington, DC, said. "A key difference is that you could fit 15 Milky Way galaxies in a row into the crater this eruption punched into the cluster's hot gas."

The explosion occurred in the Ophiuchus Supercluster, about 390 million light years from Earth. Giacintucci and her colleagues think the source was a supermassive black hole in one of the cluster's constituent galaxies - specifically jets of radiation spewing from the light-gobbling monster which are powered by inflowing gas and dust.

The possibility of an incredibly powerful Ophiuchus explosion was first raised in 2016 in a study led by Norbert Werner, which examined

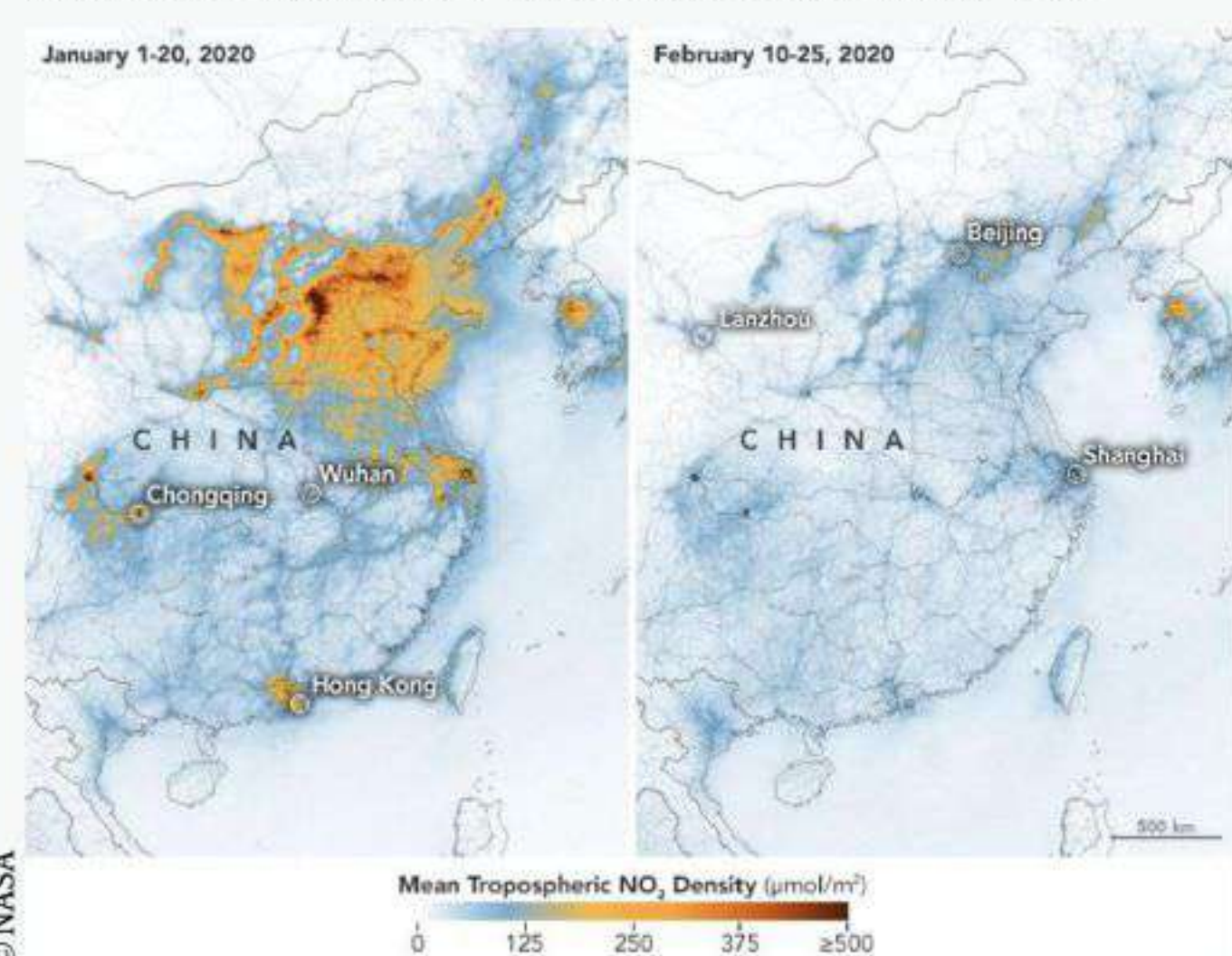
images captured by NASA's Chandra X-ray Observatory. Werner and his colleagues reported a strangely curved edge in the cluster, which could be part of the wall of a cavity formed by a blast. And what a blast it would be: the scientists calculated that it would take about five times 10^{54} joules of energy to create such a cavity.

But the 2016 study didn't establish that an explosion actually was responsible for that curved edge. Giacintucci and her colleagues just made that determination after analysing additional X-ray data from Chandra and Europe's XMM-Newton space telescope, as well as radio information gathered by the Murchison Widefield Array in Australia and the Giant Metrewave Radio Telescope in India. The combined data shows that the curved edge is part of a cavity wall, because it borders an area rich in radio emission. That emission likely resulted when the black hole's outburst accelerated electrons to nearly the speed of light.

Dramatic effect of coronavirus lockdowns seen from space

Words by Rafi Letzter

The new coronavirus' impact on China is so stark that it can be seen from space as a dramatic drop in air pollution. Orbital instruments designed to monitor air quality picked up a substantial drop in concentration of nitrogen dioxide (NO_2) pollution since January. NO_2 is a harmful substance emitted by gas vehicles, power plants and other machines that burn fossil fuels. The



© NASA

decline is likely related to an economic slowdown and travel restrictions in China since the virus became widespread.

"This is the first time I have seen such a dramatic drop-off over such a wide area for a specific event," Fei Liu, an air-quality researcher at NASA's Goddard Space Flight Center, said. A NASA Earth Observatory image shows an astonishing decline in NO_2 between January and the start of February.

Liu said that there have been other incidents that led to measurable NO_2 decreases, including the 2008 economic recession, but none have been so intense or happened so quickly. She also noted that there's often a noticeable drop-off around this time as China celebrates the Lunar New Year, but that it's never before been so stark. "This year the reduction rate is more significant than in past years and it has lasted longer," she said. "I am not surprised because many cities nationwide have taken measures to minimise spread of the virus."

Left: Air pollution reduction is most noticeable around Beijing

Right: SpaceX's Starship is at the forefront of the company's Martian colonisation goals

WIN

MEADE LIGHTBRIDGE MINI 130 TELESCOPE AND HAMA LED TORCH

Courtesy of Hama UK Ltd, this stellar duo is waiting to be won to reveal a host of amazing astronomical sights

The Meade LightBridge Mini 130 telescope and the Hama Multifunctional LED Torch make a formidable pairing when it comes to observing the night sky. The LightBridge Mini 130 flaunts a parabolic Newtonian reflector with an aperture of 130 millimetres (5.1 inches), which enables it to magnify a variety of sensational stars, planets and other celestial objects to an incredible resolution. Additionally, the telescope sits upon a flat, rotating base and a single-arm mount, allowing for easy azimuth and altitude movement through the night sky.

The Hama Multifunctional LED Torch is not just a great pocket companion: with its red-light capability, it is an essential tool for all astronomers in preserving night vision. Setting up telescopes and reading planispheres on a dark night can be challenging, but using Hama's LED torch you can do both without spoiling your view of the night sky's treasures.



To be in with a chance of winning, answer this question:

What is the name of Blue Origin's robotic payload carrier and lunar lander, which was announced in May 2019?

A: Lunar Express **B:** Blue Moon **C:** New Armstrong

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30 YEARS OF HUBBLE

Celebrating three decades of an icon of science –
and a triumph of technology

Reported by Andrew May

It's 30 years since NASA launched the Hubble Space Telescope into orbit on 24 April 1990. It was carried aloft in the payload bay of Space Shuttle Discovery, and for three decades Hubble's history was closely intertwined with the Shuttle's. It was originally scheduled for launch in 1986, but the tragic Challenger accident at the start of that year led to a four-year delay.

When Hubble finally made it into orbit, it still wasn't plain sailing. Almost immediately a serious flaw was discovered in the telescope's mirror which made stars look slightly blurred



Left: The Hubble Space Telescope was named after American astronomer Edwin Hubble

rather than sharp pinpoints of light. Since the whole point of putting Hubble above the Earth's atmosphere was to avoid the blurring that ground-based telescopes suffer from, this was disastrously bad news. For any other astronomical satellite the situation would have been terminal, but not Hubble. It was designed all along to be serviceable in space – another way its destiny was inextricably tied to the Shuttle.

The first servicing flight, by Space Shuttle Endeavour in December 1993, was originally planned as a routine maintenance visit. Now it was an urgent rescue mission. In a series of tense spacewalks the astronauts replaced Hubble's main camera with a redesigned one and installed a corrective optics package for the other instruments. In what may be the second greatest feat of human spaceflight after the Moon landings, Hubble was brought back up to its design spec. Now it could see all the wonders of the universe with a clarity that could never be achieved down on Earth's surface. Four subsequent servicing missions, the last by Space Shuttle Atlantis in May 2009, have ensured Hubble remains the world's most powerful telescope to this day.



WHAT THE SCIENCE TEAM LOVE ABOUT HUBBLE

"HUBBLE IS A TIME MACHINE THAT'S LET US EXPLORE BACK OVER 13 BILLION YEARS OF TIME ... JUST TO ABOUT 400 MILLION YEARS AFTER THE BIG BANG"

Garth Illingworth, former deputy director of the Space Telescope Science Institute



© NASA/ESA

Above: To most telescopes a globular cluster's core is just a blur of light, but Hubble sees individual stars

"HUBBLE IS THE FIRST FACILITY THAT HAS GIVEN US THIS UNIQUE VIEW INTO THE ATMOSPHERES OF PLANETS BEYOND OUR SOLAR SYSTEM"

Nikole Lewis, co-leader of Hubble exoplanet studies



© NASA

"IT HAS REALLY CHANGED OUR UNDERSTANDING OF HOW DYNAMIC OUR SOLAR SYSTEM TRULY IS"

Heidi Hammel, planetary astronomer who has worked on Hubble since the 1990s



© NASA

As dark as the night sky looks from ground level, it never gets completely black due to airglow in the atmosphere, which limits the ability of earthbound astronomers to take long-exposure photographs. At Hubble's high altitude, however, the background sky really is pitch black, which means it can see incredibly faint objects if it stares at the same patch of sky for long enough. That's the rationale behind one of Hubble's most impressive achievements: the 'deep-field' images, of which the first was released in 1996 and the most recent - the Hubble Extreme Deep Field (HXDF) - in 2012. **All About Space** speaks to one of the scientists behind the project, Garth Illingworth.

"Before Hubble, we knew essentially nothing about galaxies in the first half of the life of the universe," he tells us. "That's the first 7 billion

"BEFORE HUBBLE, WE KNEW ESSENTIALLY NOTHING ABOUT GALAXIES IN THE FIRST HALF OF THE LIFE OF THE UNIVERSE" **GARTH ILLINGWORTH**

years of the universe's 13.8-billion-year life. Now Hubble, through remarkable surveys like HXDF, has probed into the era of the first galaxies." As a specific example Illingworth cites GN-z11, the most distant galaxy discovered by Hubble. "Just 400 million years after the Big Bang, Hubble is looking back through 97 per cent of all time to see GN-z11, far outstripping what can be done with the biggest telescopes on the ground."

Although Hubble is best known for the spectacular images taken with its cameras, these are complemented by other, equally important instruments in the form of spectrographs. The latter add a whole new dimension, as Hubble's senior project scientist Jennifer Wiseman explains. "The spectrum taken with the STIS spectrograph on Hubble tells you about the composition of the gases and the material in the system, and the motions of the material as well. Having cameras and spectrographs gives you a very powerful combination of scientific tools."

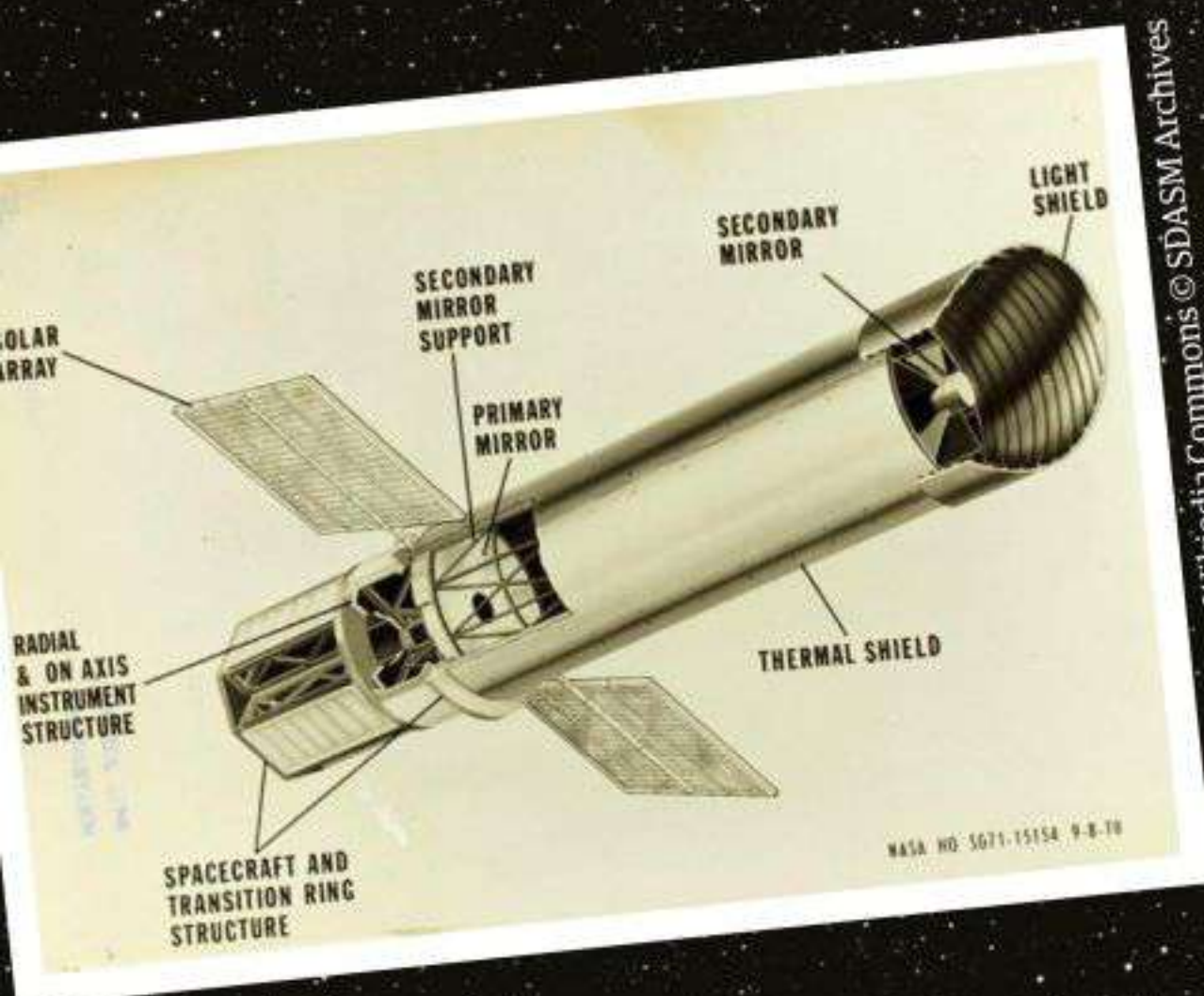
Perhaps the most dramatic use of Hubble's spectrographs - and one that few astronomers would have envisioned when it was launched 30 years ago - is in exploring the atmospheres of recently discovered exoplanets around distant stars. "This technique called transmission spectroscopy has been leveraged about 100 times," explains

THE MAKING OF A SPACE TELESCOPE

1970

Launch minus 20 years

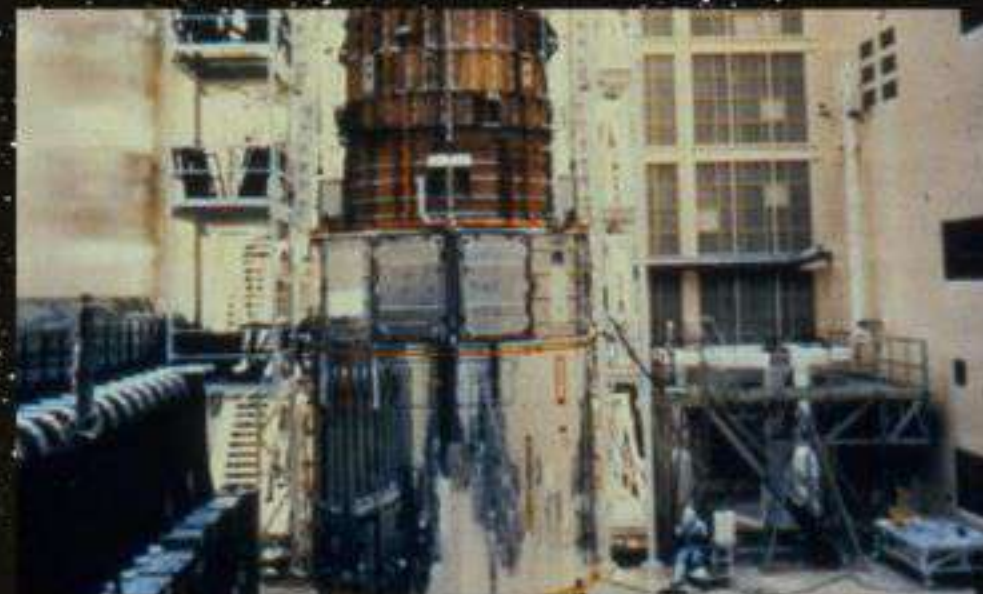
NASA's aspirations to launch a 'large space telescope' go back a long way, and this 1970 conceptual drawing already looks distinctly Hubble-like.



1985

Launch minus 5 years

By early 1985 Hubble was finished and scheduled for launch the following year - then it was delayed by the tragic Challenger accident in January 1986.



APRIL 1990

The good news ...

After a four year wait, Hubble was finally blasted into space on board Space Shuttle Discovery on 24 April 1990, blasting off from the Kennedy Space Center.



... and the bad news

Within weeks of launch it became clear there was a serious problem with Hubble's optics. Stars that should have been sharp pinpoints looked horribly blurred.



Another rescue mission

By late 1999 a series of gyro failures meant Hubble needed more repairs - carried out by, among others, British-born astronaut Michael Foale, seen in action below.



In-service upgrade

Another servicing mission installed two new scientific instruments, the Space Telescope Imaging Spectrograph (STIS) and Near Infrared Camera and Multi-Object Spectrometer (NICMOS).



Shuttle to the rescue

A complex repair mission got Hubble working the way it was supposed to. The photo below shows astronauts wrapping up after five days of spacewalks.



MARCH 2002

A new camera

The fourth servicing mission saw the last of Hubble's original instruments replaced with this one - the Advanced Camera for Surveys (ACS).



DECEMBER 1999

The final servicing mission

The Space Shuttle's last visit to Hubble, involving a thorough overhaul, was almost 11 years ago - the last time anyone saw it at close quarters.

FEBRUARY 1997

Pillars of Creation redux

Improvements made during the servicing missions meant that when Hubble revisited one of its 'greatest hits', the result was even more spectacular than the original.

DECEMBER 1993



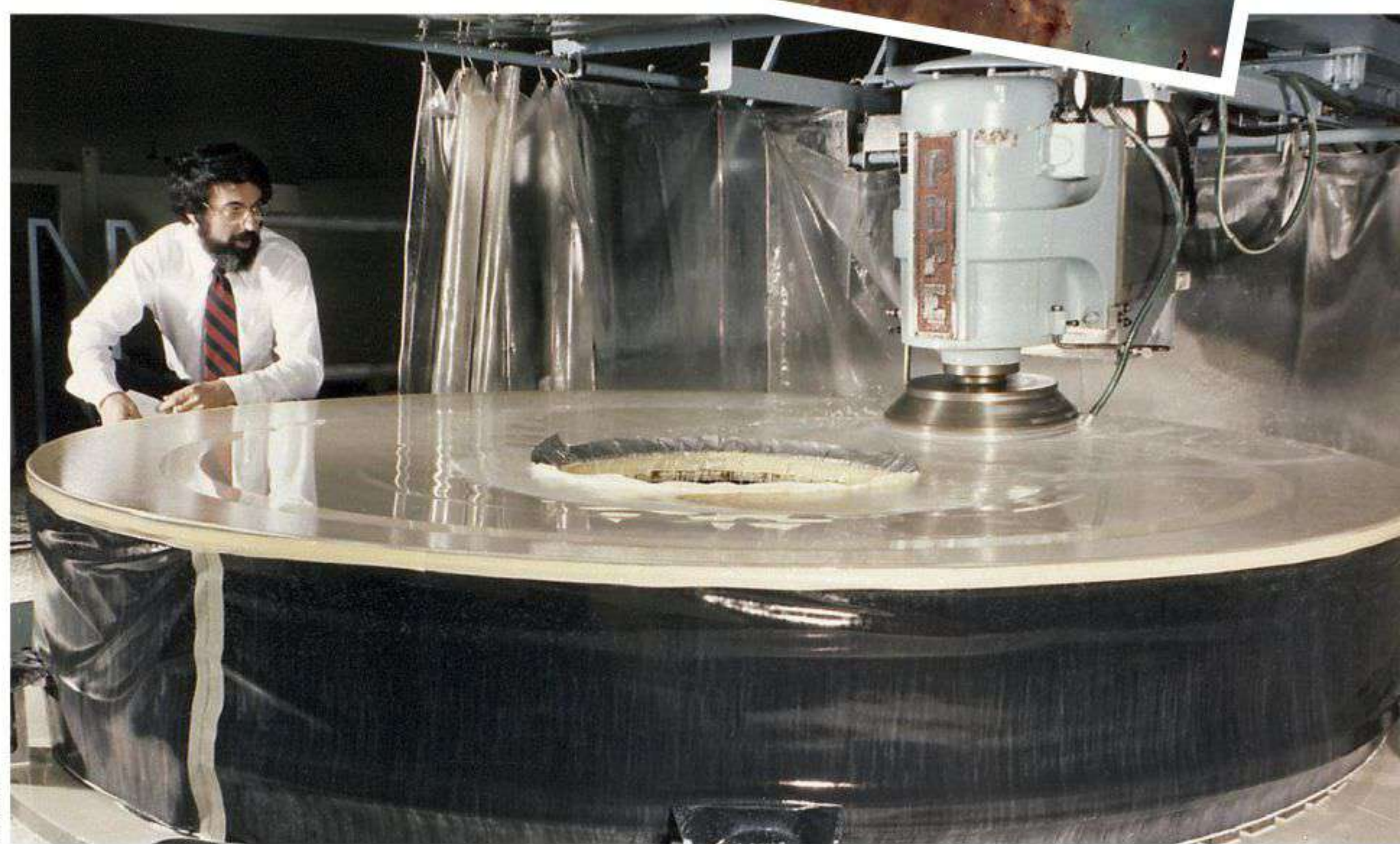
MAY 2009

OCTOBER 2014

exoplanet specialist Nikole Lewis. "We can actually look at starlight filtered through those planet atmospheres to find out something about what's in the air around these planets beyond our Solar System." It's particularly exciting to find traces of chemicals which, on Earth, we associate with life - water being the most obvious one. Hubble made headlines in 2019 with the first discovery of water in the atmosphere of an Earth-like exoplanet - in this case K2-18b, which orbits in the habitable zone of a red dwarf star.

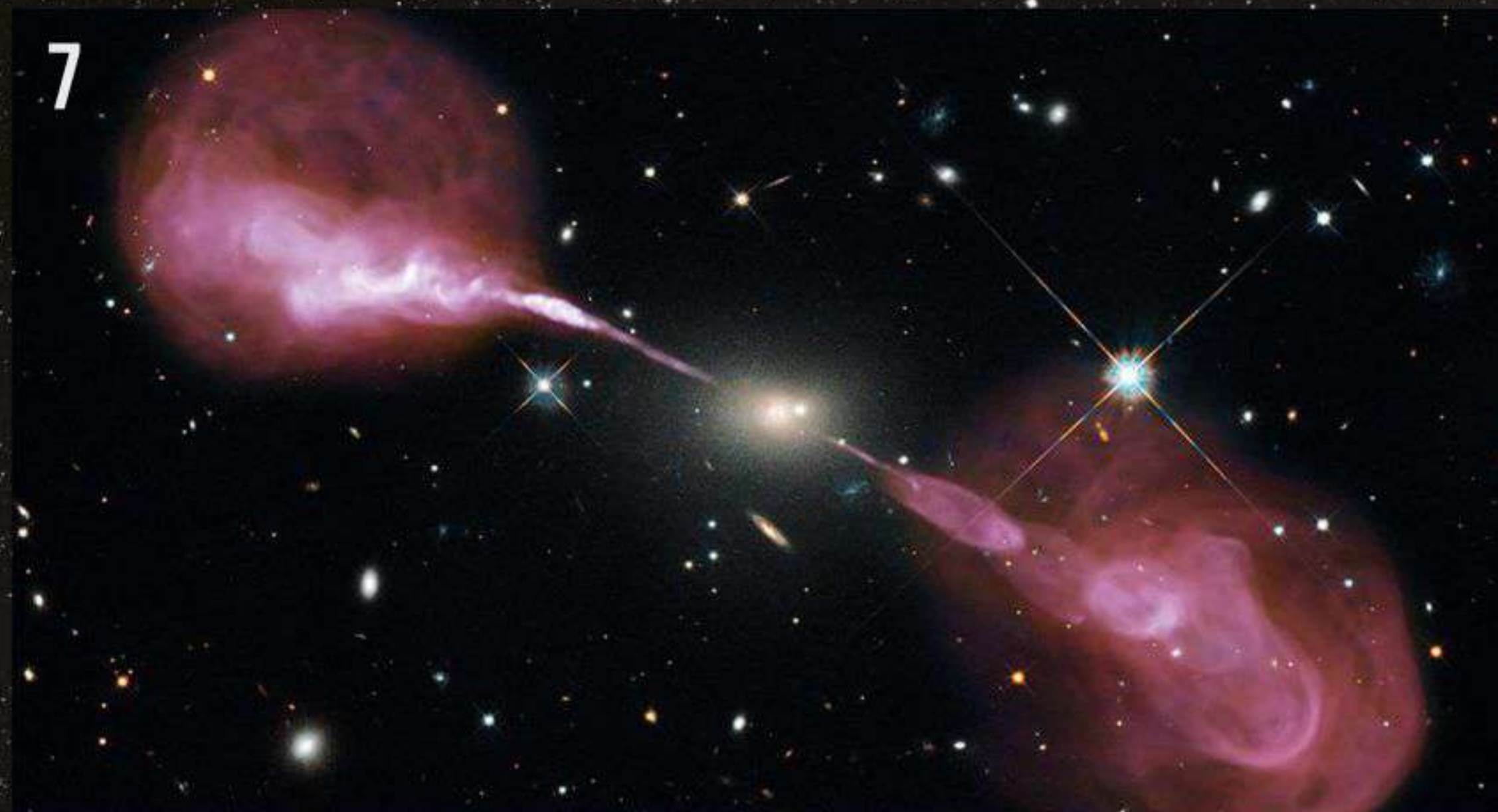
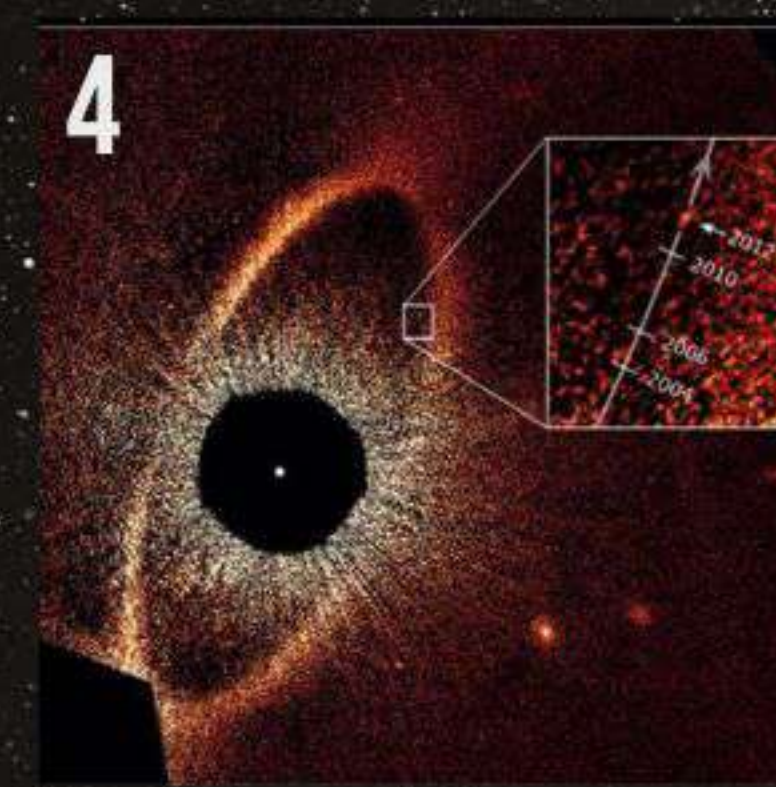
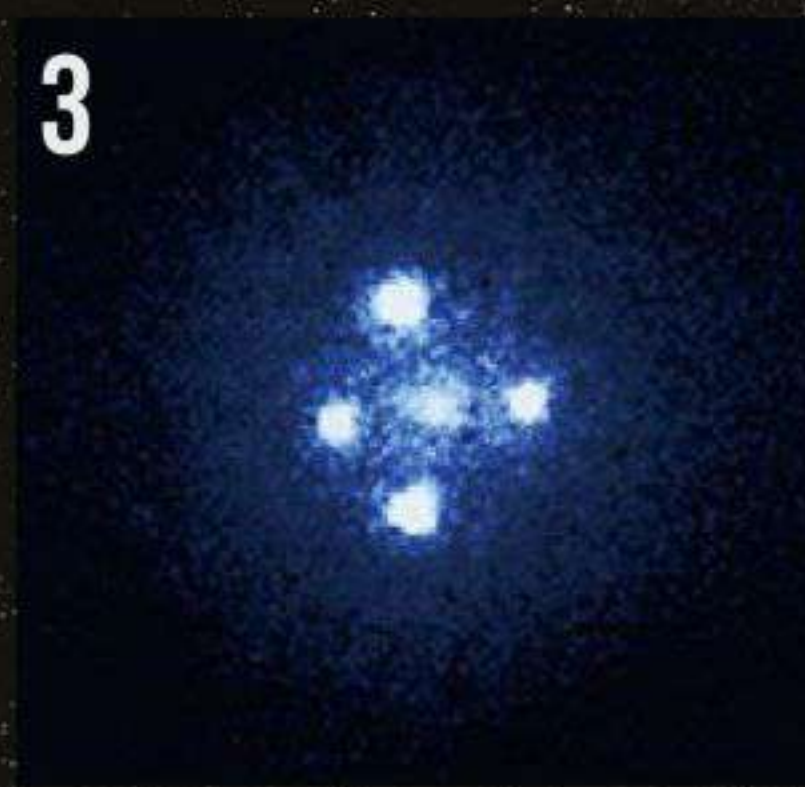
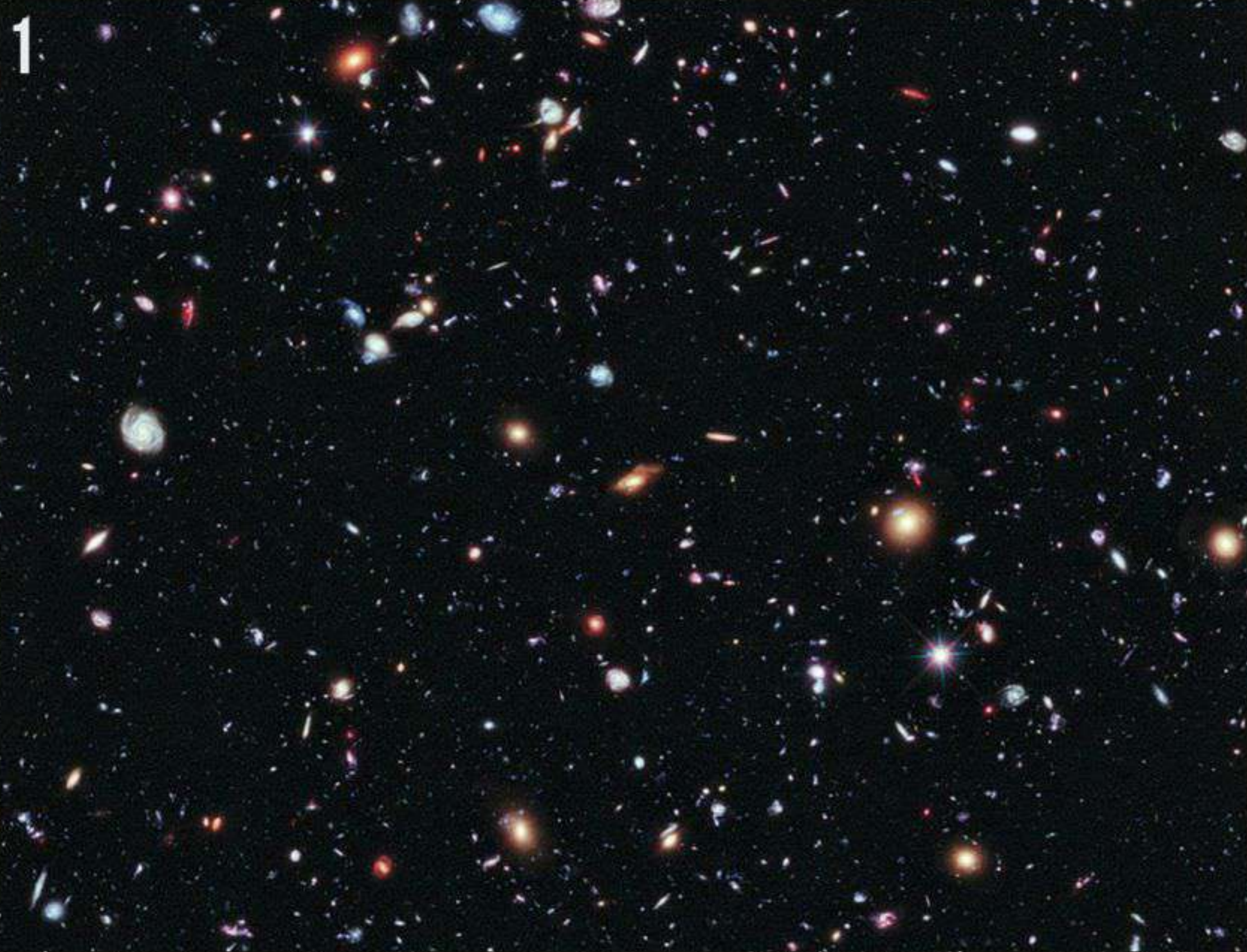
In its 30 years in space, the Hubble Space Telescope has contributed to every aspect of astronomy - from our own Solar System to the most distant galaxies - and more than 15,000 scientific papers have been published detailing its results. These include many exciting new discoveries,

Right: A photograph from March 1979 showing the fabrication of Hubble's main mirror



WHAT HAVE WE LEARNED FROM HUBBLE SO FAR?

The space telescope has made fascinating new discoveries in every branch of astronomy. Here are some highlights



1 This is the Hubble 'Extreme Deep Field' image released in 2012. It's a tiny area of the sky, photographed with an effective exposure time of 23 days. That means it can pick out hundreds of galaxies that are so faint - and so distant - that they've never been seen before.

2 In October 2019 Hubble provided the clearest image yet of an interstellar comet. This is 2I/Borisov, only the second interstellar visitor to be detected after 'Oumuamua in 2017. This image was taken when 2I/Borisov was nearly 420 million kilometres (260 million miles) from Earth.

3 Hubble has given us unprecedented views of gravitationally lensed quasars - distant objects we see in distorted form due to the bending of light around an intervening galaxy. This is the 'Einstein Cross' - a multiple imaged quasar taken by Hubble's Faint Object Camera.

4 Exoplanets are usually detected by indirect methods, but Hubble can see some of them directly. This example is Fomalhaut b, orbiting its parent star amid a vast belt of debris. The star is blocked out using a coronagraph, allowing the planet to be seen.

5 Earth isn't the only planet to experience the phenomenon of aurorae - Hubble has observed dramatically scaled-up versions around the poles of Jupiter and Saturn too. This ultraviolet image of Jupiter's aurora was taken by Hubble in support of NASA's Juno mission.

6 One of Hubble's first major discoveries was the observation of protoplanetary discs - called proplyds for short - around young stars, particularly in the highly active star-forming region of the Orion Nebula. This image, released in 1995, shows just one of Orion's many proplyds.

7 One of the great things about Hubble is how it can be used in combination with other telescopes. Here's Hubble's view of galaxy Hercules A, with data from the Very Large Array radio telescope superimposed. The latter shows two jets powered by its supermassive black hole.

SPACE TELESCOPE SUCCESSOR

James Webb will be bigger than Hubble – but it's not a straight replacement

In 2003 NASA commissioned a successor to Hubble, called the James Webb Space Telescope (JWST) after former administrator James Webb, who oversaw the creation of NASA's human spaceflight program in the 1960s. The JWST will be different from Hubble in many ways. Its main mirror, instead of a single piece of glass, will be made from 18 hexagonal segments, giving it a diameter of 6.5 metres (21 feet). It will be able to see even fainter objects at even greater resolution. But it won't see them at the same wavelengths as Hubble, which spans 100 nanometres (nm) in the ultraviolet to 2,500nm in the infrared – for comparison, your eye sees from 380 to 740nm. JWST is essentially an infrared telescope, optimised for 600 to 28,000nm. It won't be able to see green or blue light, just orange and red, together with much longer wavelengths beyond that.

JWST optics

An 18-element, 6.5-metre (21-foot) mirror feeding two cameras and two spectrographs optimised for infrared.

JWST orbit

Will be located at the Sun-Earth Lagrangian point L2, approximately 1.5 million kilometres (932,056 miles) from Earth.

Hubble orbit

Orbiting 540 kilometres (336 miles) above the surface of Earth, this gives a more obstructed view than L2, but meant the Shuttle could make servicing visits.

Hubble optics

A single mirror feeding two cameras and two spectrographs with a range of capability from near-infrared to near-ultraviolet.

from the supermassive black holes lurking in the centres of galaxies to the mysterious 'dark energy' that's responsible for the accelerating expansion of the universe. One Hubble scientist, Adam Riess of NASA's Space Telescope Science Institute (STScI), was awarded a share of the 2011 Nobel Prize for his part in the discovery of this effect.

As the senior project scientist for Hubble, it's Jennifer Wiseman's job to keep track of the full range of Hubble's scientific activities in different areas of astronomy. **All About Space** asks her how things are going. "30 years into the mission, the scientific productivity of Hubble is at an all-time high," she tells us. "The reason is that the servicing

missions, especially the final one in 2009, have been very successful, keeping Hubble very fit for great observations and cutting-edge science. Also, clever new observing techniques developed by Hubble scientists have boosted new discoveries as well. And the outstanding expert operations team on the ground – engineers, technicians, managers, and computer support – keep diligent watch over Hubble's subsystems to keep science return at a maximum as Hubble ages."

So what's the payoff for the scientific community? "Currently there are almost a thousand science papers published every year based on data from Hubble," Wiseman says. "That's more than ever before. About half of these are based on data taken from the Hubble archive. This is fantastic. It means that data originally taken for one scientific purpose is being used again for a different scientific purpose – a great return on investment!"

Some of the scientists who work with Hubble today were still at school – or not even born – when it was launched 30 years ago, while others have been closely involved with it throughout that time. In the latter category is Colin Norman, a senior staff member at STScI who was an eyewitness to Hubble's launch from Cape Canaveral in April

Left: The Corrective Optics Space Telescope Axial Replacement (COSTAR) was key to repairing Hubble's mirror problem

WHAT THE SCIENCE TEAM LOVE ABOUT HUBBLE (CONTINUED)

"WE'RE USING HUBBLE TO INVESTIGATE BIG QUESTIONS ABOUT THE UNIVERSE (LIKE DARK ENERGY) THAT WERE NOT ANTICIPATED WHEN HUBBLE WAS ORIGINALLY LAUNCHED"

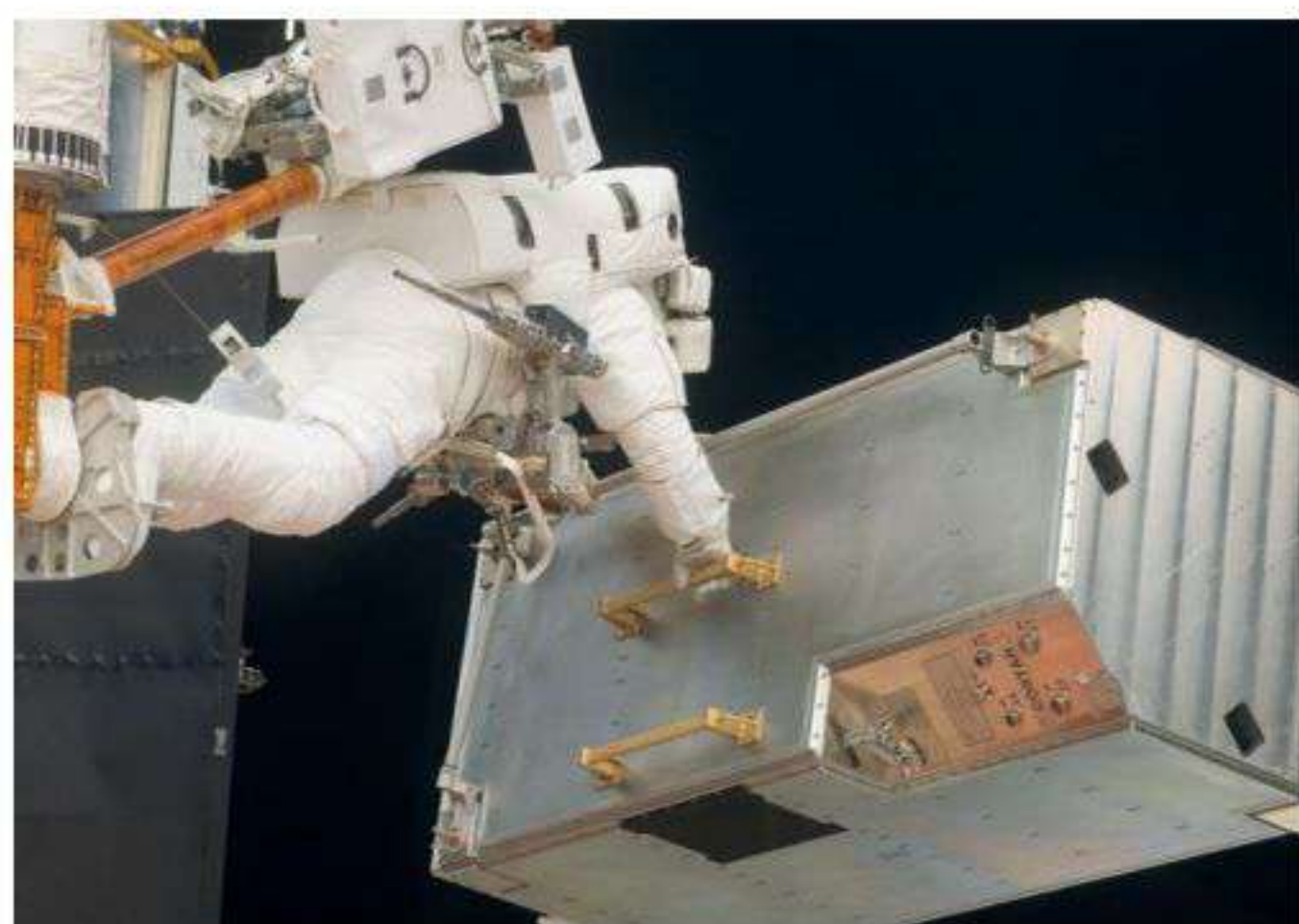
Jennifer Wiseman, Hubble senior project scientist

"A GAME CHANGER FOR CIVILISATION'S PERCEPTION OF THE UNIVERSE AND OUR PLACE IN THE UNIVERSE"

Ray Villard, news director for the Space Telescope Science Institute

"THE HUBBLE TENSION BETWEEN THE EARLY AND LATE UNIVERSE MAY BE THE MOST EXCITING DEVELOPMENT IN COSMOLOGY IN DECADES"

Adam Riess, senior staff member at the Space Telescope Science Institute



HUBBLE'S GREATEST IMAGES

1991 - 2020

1991



◀ CYGNUS LOOP

Taken in April 2001, this image shows part of the Cygnus Loop supernova remnant, a bubble-like blast wave expanding outwards from a colossal stellar explosion that occurred some 15,000 years ago.

1997

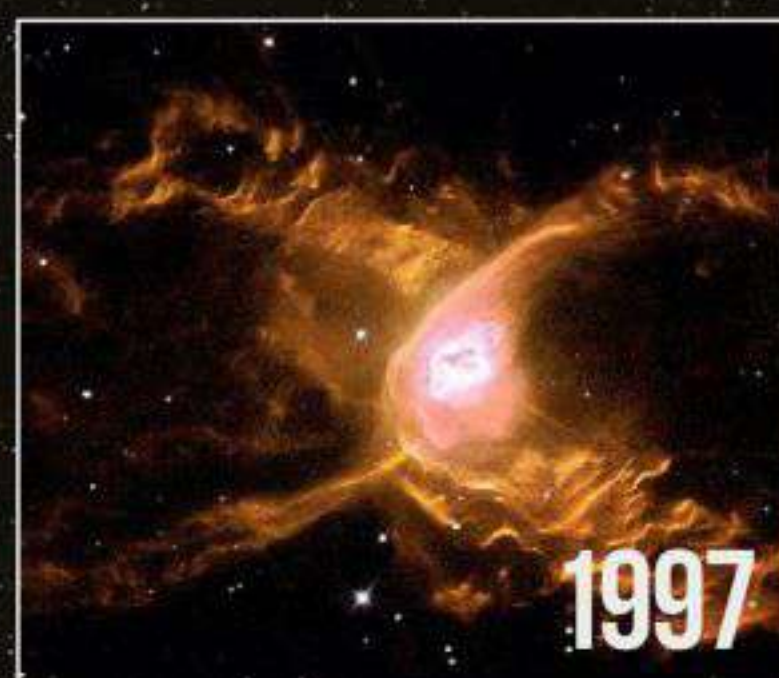


SATURN ▲

You could easily mistake this photograph for a close-up image of Saturn taken by a passing space probe. The horizontal bands, caused by strong winds in the planet's dense atmosphere, are clearly visible.

RED SPIDER NEBULA ▶

Here's another planetary nebula, NGC 6537 in Sagittarius. It's a double-lobed nebula, which despite its nickname - the Red Spider - looks more like a delicate butterfly than an arachnid in this beautiful image.



1997

HUBBLE DEEP FIELD ▶

This is Hubble's first 'deep-field' image taken in 1995. It's an ultra-long-exposure photograph of a tiny patch of sky, revealing hundreds of galaxies - many of them far more distant than anything that had been seen before.



1995

1998



◀ ROTTEN EGG NEBULA

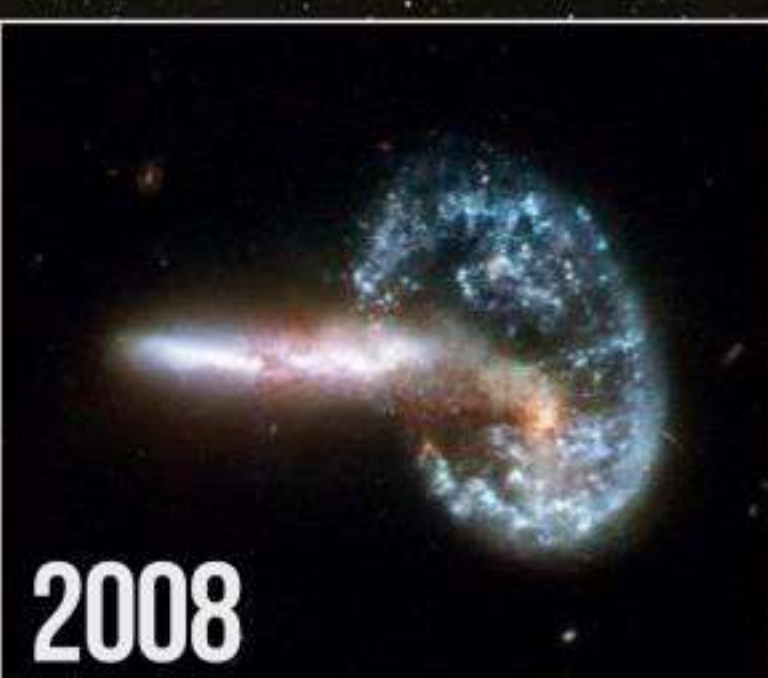
The 'Rotten Egg Nebula' may have an unattractive name, but it's far from unattractive, as this colourful image shows. It shows the subtle variations in physical properties of the outflowing material making up the nebula.



1999

◀ ESKIMO NEBULA

One of the first images taken after the third servicing mission by Discovery in December 1999, this shows NGC 2392 - better known as the 'Eskimo Nebula' for its resemblance to a human face in a furry hood.



2008

◀ ARP 148

The anniversary image for 2008 was actually a montage of 59 pairs of colliding galaxies. Here is just one of the pairs, Arp 148, described by NASA as "the staggering aftermath of an encounter between two galaxies".



2007

◀ CARINA NEBULA

On the 17th anniversary of Hubble's launch in April 2007, NASA began a new tradition of releasing an official anniversary image. This first one shows the swirling clouds of gas and dust in a portion of the Carina Nebula.



2006

2009



◀ ARP 194

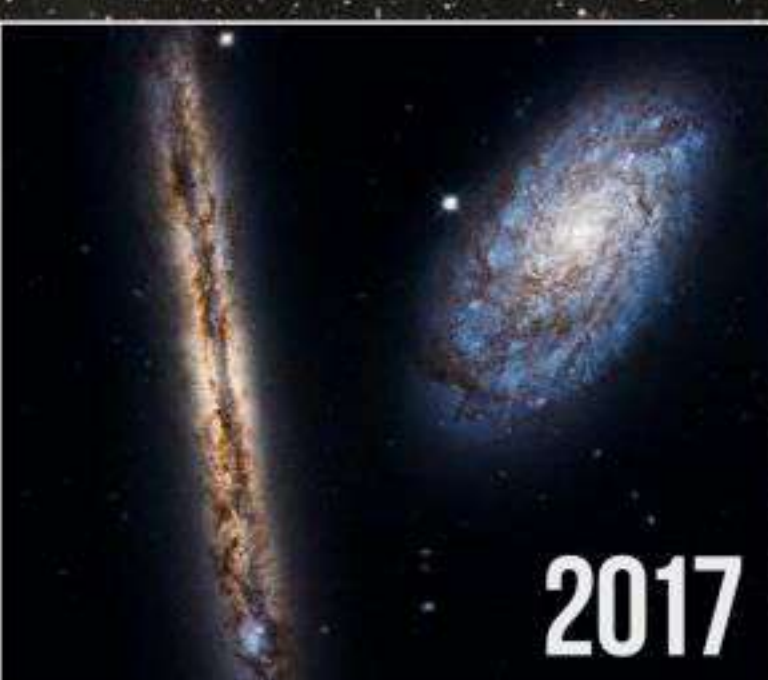
Colliding galaxies featured again in this anniversary image. Rather than a pair of galaxies, Arp 194 consists of three of them all interacting with each other. The bright-blue areas are created by swarms of newborn stars.



2010

◀ MYSTIC MOUNTAIN

Called the 'Mystic Mountain', this image was released to mark the telescope's 20th anniversary in 2010. It shows part of the Carina Nebula - actually a tiny detail from the area covered in the 2007 anniversary image.



2017

◀ NGC 4302 AND NGC 4298

For its 2017 anniversary image, the Hubble team picked this dramatic view of a pair of galactic neighbours. They're almost perpendicular to each other, so we see the first of them edge-on and the other face-on.



2016

◀ BUBBLE NEBULA

NGC 7635 is an emission nebula 8,000 light years away in Cassiopeia. Looking at this amazing photograph, released as the anniversary image for 2016, it's easy to see how it got its nickname the 'Bubble Nebula'.



2014

LAGOON NEBULA ▶

A particularly colourful emission nebula featured in the 2018 Hubble anniversary image in the form of the Lagoon Nebula - Messier 8 or NGC 6523 - a giant interstellar cloud in the constellation Sagittarius.



2018

2019



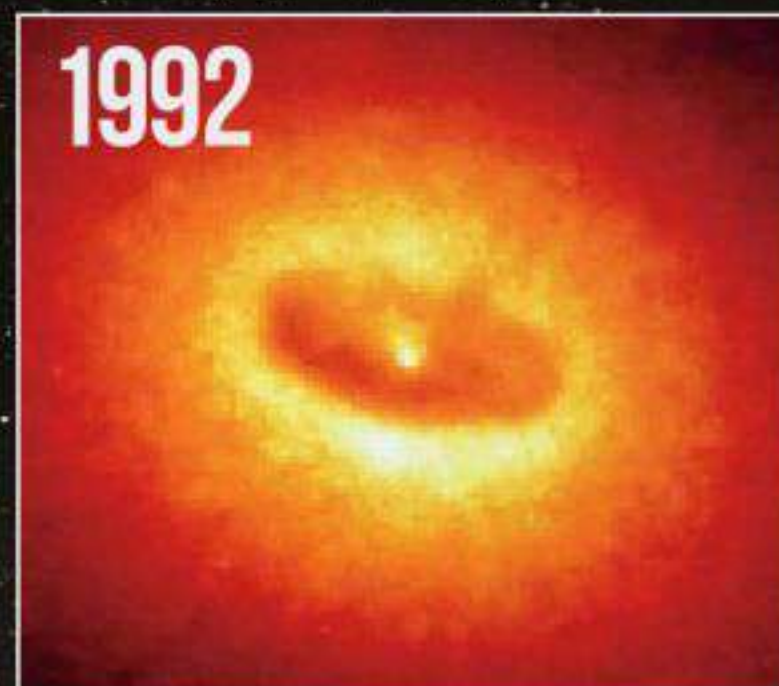
◀ THE SOUTHERN CRAB NEBULA

The famous Crab Nebula has a lookalike in the form of an otherwise unrelated planetary nebula in the Southern Hemisphere. This 'Southern Crab Nebula' starred as the Hubble anniversary image last year.



◀ JUPITER

This was Hubble's first full-colour snapshot of Jupiter, created by superimposing three images taken with red, green and blue filters. The Great Red Spot, a hurricane-like formation larger than the Earth, is clearly visible.



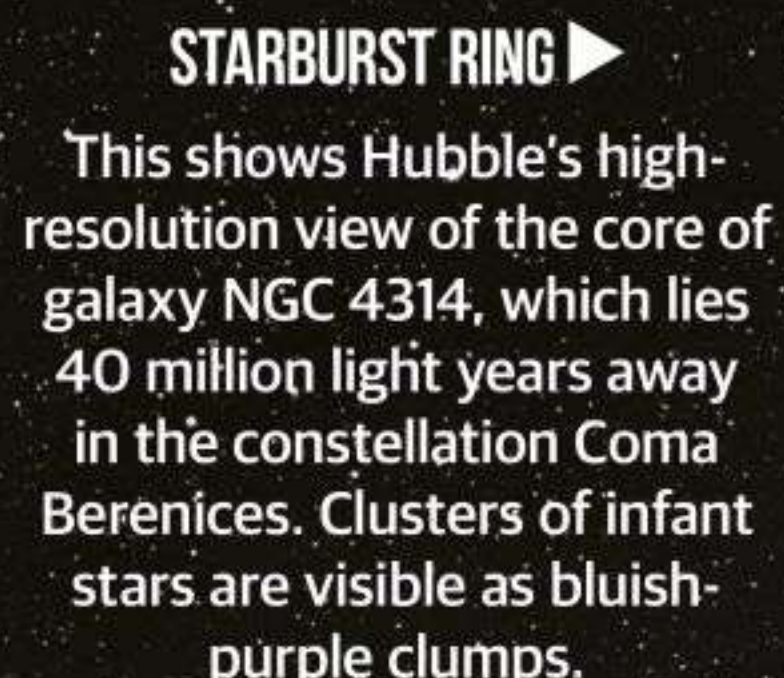
◀ SUPERMASSIVE BLACK HOLE?

This image shows the core of the giant elliptical galaxy NGC 4261 in the Virgo Cluster, 100 million light years away. It's believed to show the hot disc of material surrounding a black hole with a mass 10 million times that of the Sun.



▲ SHOEMAKER-LEVY 9

In July 1994, fragments of comet Shoemaker-Levy 9 crashed into Jupiter. This ultraviolet image taken by Hubble shows the huge scars that the impact created in Jupiter's atmosphere - larger than our own planet.



▶ STARBURST RING

This shows Hubble's high-resolution view of the core of galaxy NGC 4314, which lies 40 million light years away in the constellation Coma Berenices. Clusters of infant stars are visible as bluish-purple clumps.



▶ PILLARS OF CREATION

The first truly iconic image, this original 'Pillars of Creation' photo dates from April 1995. It shows part of the Eagle Nebula, a star-forming region 6,500 light years away in the constellation Serpens.



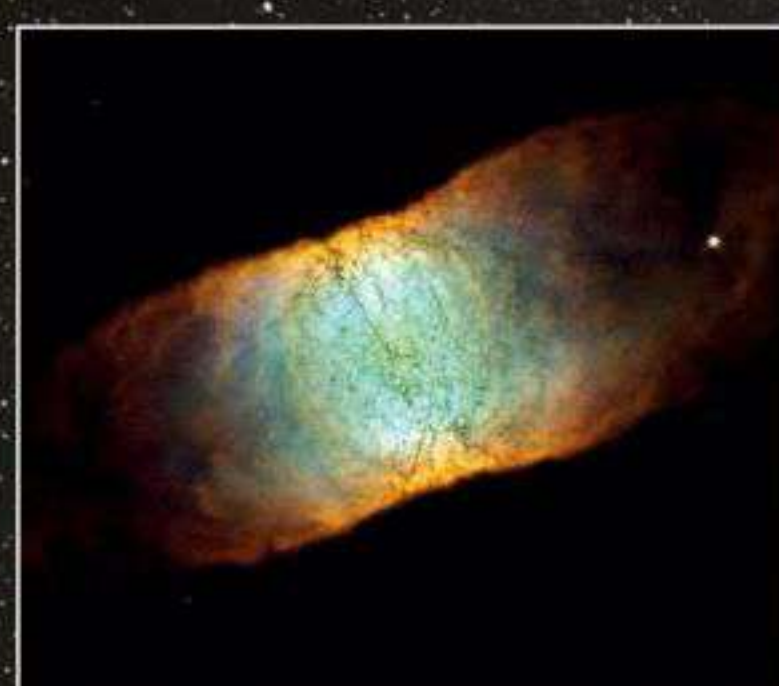
▶ HELIX NEBULA

Here's another strikingly eye-like planetary nebula - this time the Helix Nebula, NGC 7293 in Aquarius. A 'mere' 690 light years away, it's one of the closest planetary nebulae to Earth - and one of the most striking.



▶ RETINA NEBULA

Here's another gorgeous planetary nebula, IC 4406, in the Southern Hemisphere constellation of Lupus. It's been dubbed the 'Retina Nebula' due to its resemblance to the retina of a human eye.



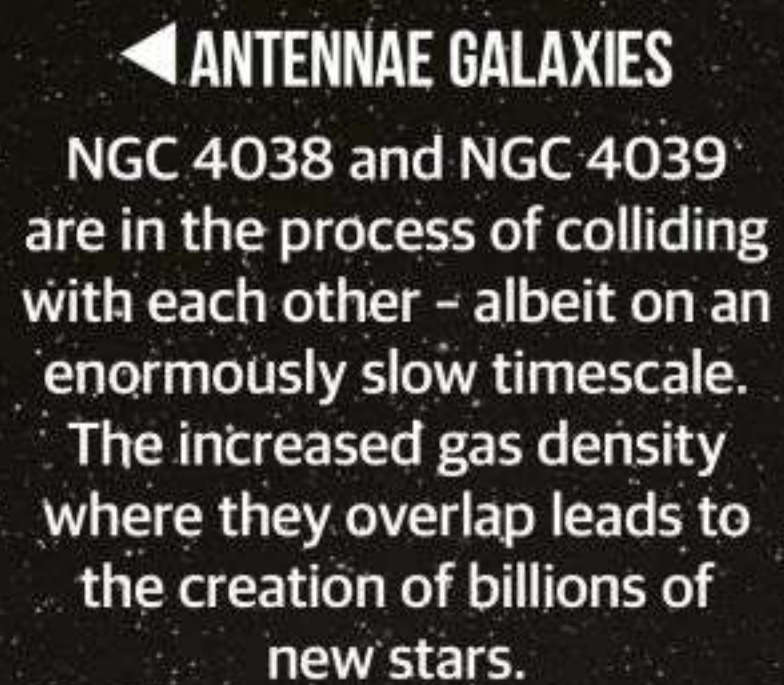
◀ WHIRLPOOL GALAXY

If you're an amateur astronomer you'll be familiar with the Whirlpool Galaxy - M51 in Canes Venatici. But you'll never have seen it with the amazing clarity of this image, released to celebrate Hubble's 15th anniversary.



◀ 'STARRY NIGHT'

Two years before this photo was taken, supergiant star V838 Monocerotis gave off a sudden pulse of light, creating an expanding halo of light around it. This image is likened to van Gogh's famous painting *Starry Night*.



◀ ANTENNAE GALAXIES

NGC 4038 and NGC 4039 are in the process of colliding with each other - albeit on an enormously slow timescale. The increased gas density where they overlap leads to the creation of billions of new stars.



◀ A GALACTIC ROSE

For Hubble's 21st birthday in 2011, NASA released this lovely picture of another pair of interacting galaxies, Arp 273, in a composition that looks uncannily like an impressionistic painting of a rose.



◀ TARANTULA NEBULA

A region of ionised gas in the Large Magellanic Cloud, low-resolution photos taken by Earth-based telescopes do look a little like the giant spider after which it's named, but any resemblance is lost in this detailed view.



2010

◀ CELESTIAL FIREWORKS

For Hubble's 25th anniversary, NASA released this image of Westerlund 2. The cluster contains some of the galaxy's hottest and brightest stars, which etch away at the enveloping gas cloud with torrential stellar winds.



◀ MONKEY HEAD NEBULA

The same constellation that hosts the Horsehead Nebula, Orion, also boasts a less well-known feature nicknamed the 'Monkey Head Nebula' - an emission nebula formally known as NGC 2174.



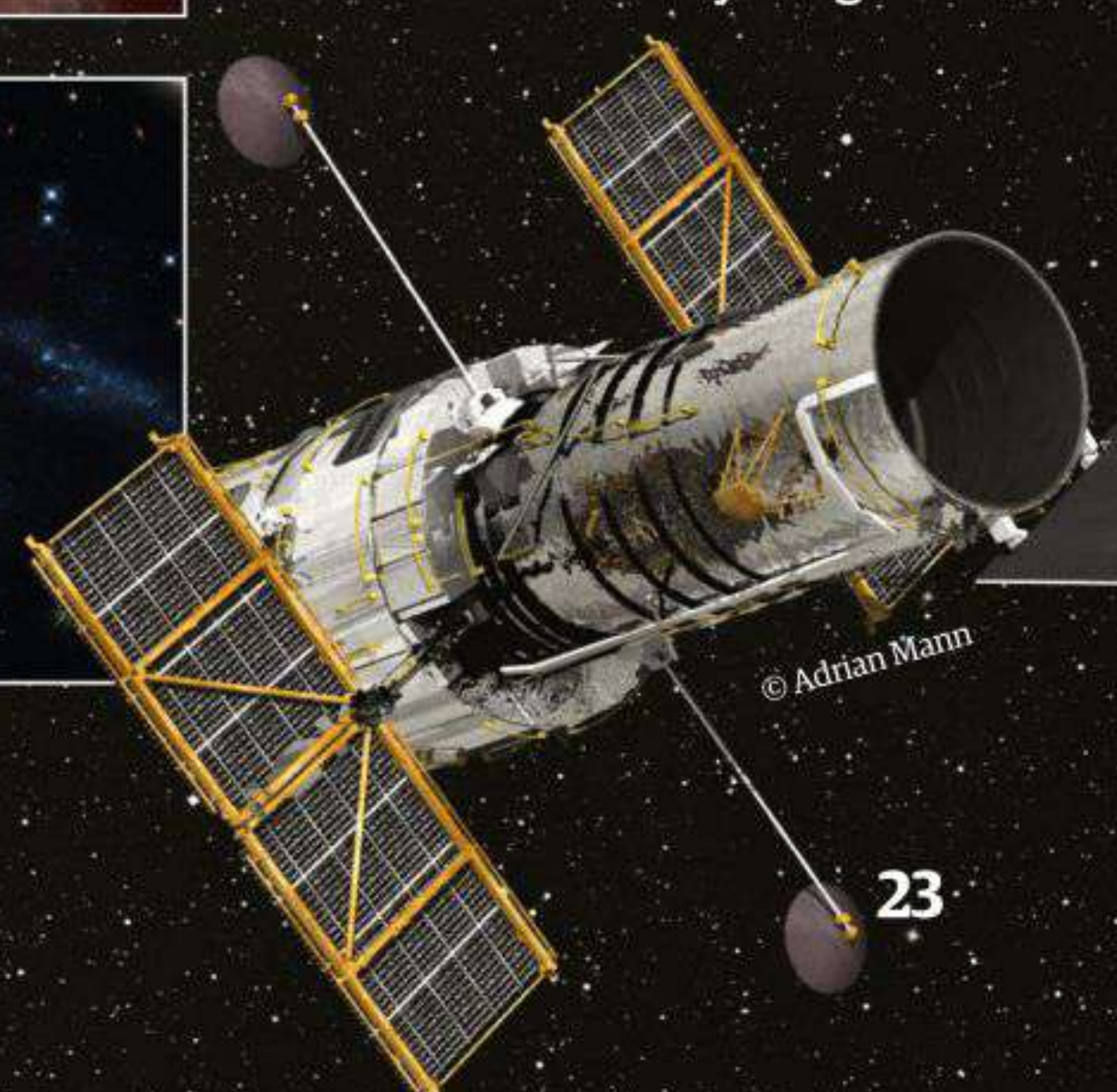
◀ HORSEHEAD NEBULA

Like the Whirlpool Galaxy, the Horsehead Nebula is another favourite sight for amateur astronomers. It looks dramatically different, however, when viewed in infrared light - as in this Hubble anniversary image.



▶ RUBIN'S GALAXY

As Hubble's 30th anniversary approached, NASA released this majestic image of the galaxy UGC 2885 in January 2020. A veritable giant, it's been designated Rubin's Galaxy after the astronomer Vera Rubin.



1990. We ask him to sum up his feelings about the last 30 years: "Hubble has changed the landscape of astronomy and astrophysics," he tells us. "It has far exceeded its early goals - no other science facility has ever made such a range of fundamental discoveries. It's been a privilege to be associated with this effort that has become embedded in the culture of our time."

That last point is an interesting one. For all its groundbreaking scientific discoveries, Hubble's most unique achievement is arguably the inspirational impact it's had on the general public. It would be an understatement to say it's the most famous telescope in history. Before Hubble, people without a special interest in astronomy probably couldn't have named a single telescope. Yet today 'Hubble' is a household name, instantly recognisable to people all over the world and a symbol of both the brilliance of human ingenuity and the wonders of the universe.

What's the reason for Hubble's uniquely iconic status? Ray Villard, STScI's news director, thinks he has the answer. "It reads like a movie script; it has a story arc," he says. "The anticipation of launch, the optical failure, redemption with the servicing missions - then more drama when it was cancelled in the last decade." Fortunately that cancellation was averted, and Hubble is still with us - hopefully for many years to come. As Villard says, "Well towards 2030 we're back to doing some of the best science we think we can ever do with Hubble."

Right: Mike Massimino flew on the fourth Hubble servicing mission, STS-109

MIKE MASSIMINO: "I'D BROKEN HUBBLE AND I WAS ALONE IN SPACE"

Mike Massimino had made a huge error. What's more, he didn't have backup while his fellow astronauts looked on

Mike Massimino and fellow astronaut Mike Good were completing a spacewalk where they sought to repair Hubble's imaging spectrograph, an instrument used to detect far-off planets and black holes. More than 100 new space tools were developed for the spacewalk, but Massimino ended up yanking a handrail away with his hands. It had been blocking the access panel to the power supply, but one of the screws was stripped, making it impossible to come off. He did this while lapping the Earth at 28,164 kilometres (17,500 miles) per hour.

"We were going to use a large number of tools during a mission to repair the failed power supply of Hubble, and we had practised it for years. Although the two bolts on the top of a handrail that covered the access panel came off with no problem, the bolt on the bottom right did not. Instead, the head of the bolt was stripped out, and when I took

a closer look, I spun my tool inside of it and destroyed any chance of being able to undo that screw. This meant the handrail wasn't going to come off and I wasn't going to be able to get to the main electronics board. This meant we were never going to be able to replace the power supply, never get Hubble back running and never find out there was life on other planets - and I was going to be blamed. That was pretty much my thought process, but the team on the ground started to troubleshoot and I started trying not to make things worse in space.

It took them about an hour or so to come up with a solution - and that time felt like an eternity out there. All the while the Sun's coming up and down and I'm wondering whether sooner or later we're going to have to knock it off and come inside because we were running out of time. But then they told me to get some tape and vice grips: I could understand vice grips because that was a tool. Tape, on the other hand, made me think we were running out of ideas. But someone had the idea of just seeing if I could yank this thing off, and they'd worked out that about 60 pounds of force was required.

I did just that, grabbing some tape from the toolbox at the front of the Space Shuttle before heading back to use it on the bottom of the handrail. I felt a deep loneliness because there was no one to help me at that specific time, but I taped the handrail, put my hand on it and knew that the reason I was using that tape was because there would be a real worry if any debris got loose. I pulled.

I managed to rip the handrail away; got it right off. I could then get to the access panel, but my power tool's battery had gone and I was also needing an oxygen refill. I put my fears aside, got more oxygen and swapped out the battery before getting on with the task. The screws came out, the new power supply went in and it worked - a successful mission from a position higher than the Space Station - and the instrument had come back to life. I then just looked at the Earth from 350 miles [563 kilometres] up.

I was out there in space, all by myself, with my own life-support system, and I could look anywhere I wanted. I could look and see the planet from where Hubble is. I thought, this would be the view from heaven. But then, I thought, it was more beautiful than that. It was like looking into a paradise. Getting to see the planet and the stars on a spacewalk was truly an incredible experience."



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Hubble has captured a vast library of images, covering everything from white dwarfs to smaller galaxy clusters and beyond

USER MANUAL

Hubble Space Telescope

With 30 years of service under its belt, the long-serving mission remains one of the greatest and most influential cosmic lenses

THE SPECS

Launch: 24 April 1990

Rocket: Space Shuttle Discovery (STS-31)

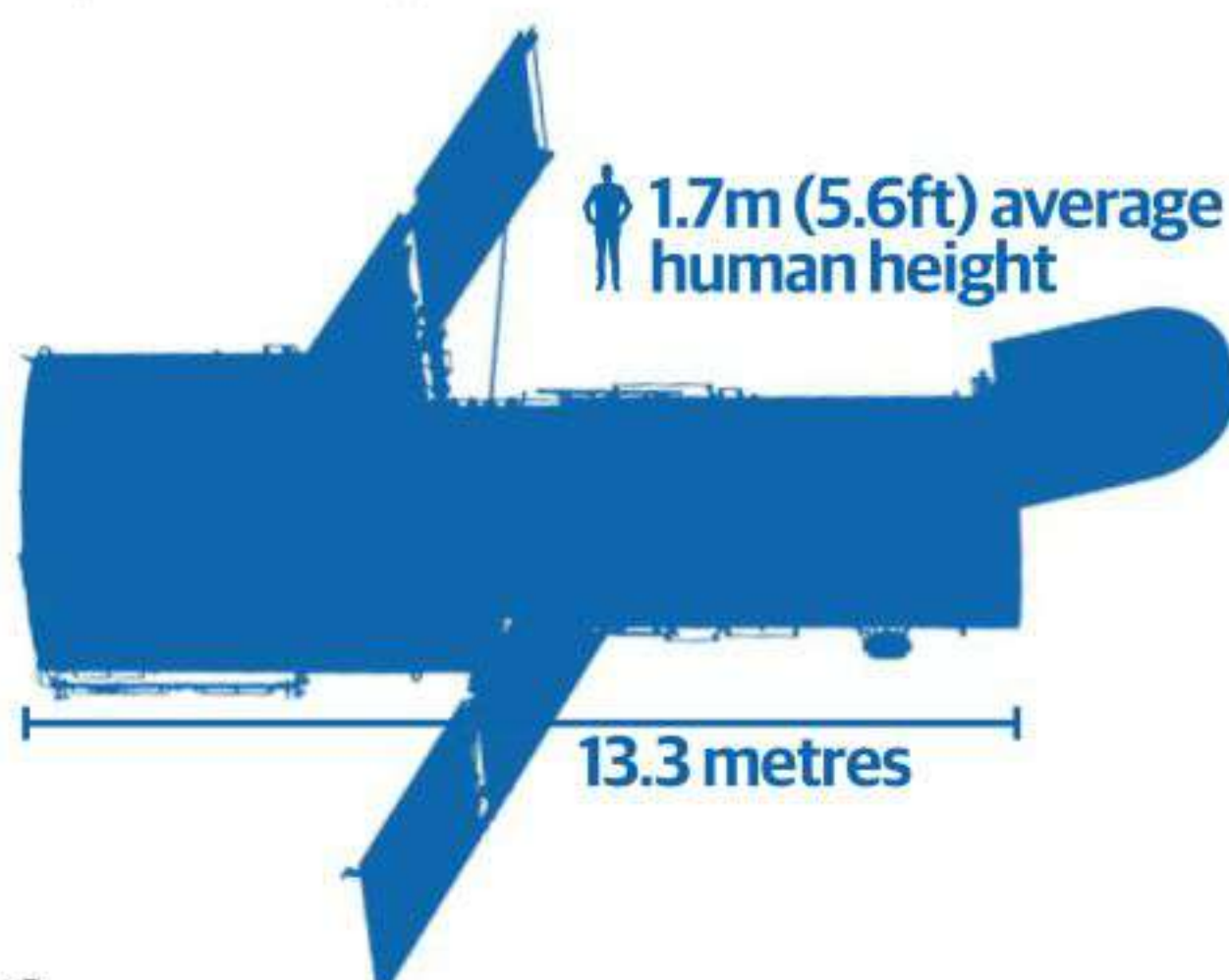
Target: Low-Earth orbit

Operators: NASA

Estimated cost: \$1.5 billion

Time in space: 30 years

Orbit height: 547 kilometres (340 miles)



Spinning high above our world in the embrace of a low-Earth orbit lies Hubble, a observatory that's served as the backbone of modern astronomy for three decades now. Its cameras have stared into the cosmos of our Solar System and beyond and have helped scientists, astronomers and academics to slowly peel back the mysteries that lie far beyond the blanket of our atmosphere.

The Hubble Space Telescope may be an ageing amalgamation of engineering from across the decades, but its impact on astronomy is truly unmatched. When it launched on 24 April 1990, Hubble represented the biggest step forward for the field since Galileo Galilei turned his homemade telescope to the stars in 1610. Humankind no longer had to rely on terrestrial observatories; it now had one high above the Earth with the power to peer far beyond our capabilities at the time.

Hubble can trace its origins as far back as the 1920s when German astronomer Hermann Oberth theorised that telescopes could be sent into space via rockets. Two decades later, American theoretical physicist Lyman Spitzer was championing that same idea. By 1969, following his proposal to Congress, NASA had turned its attention and resources to designing humankind's first true space telescope. It was an incredible project, one that

would eventually exceed \$1.5 billion (£1.2 billion) by its launch, yet it would be a rocky road to takeoff.

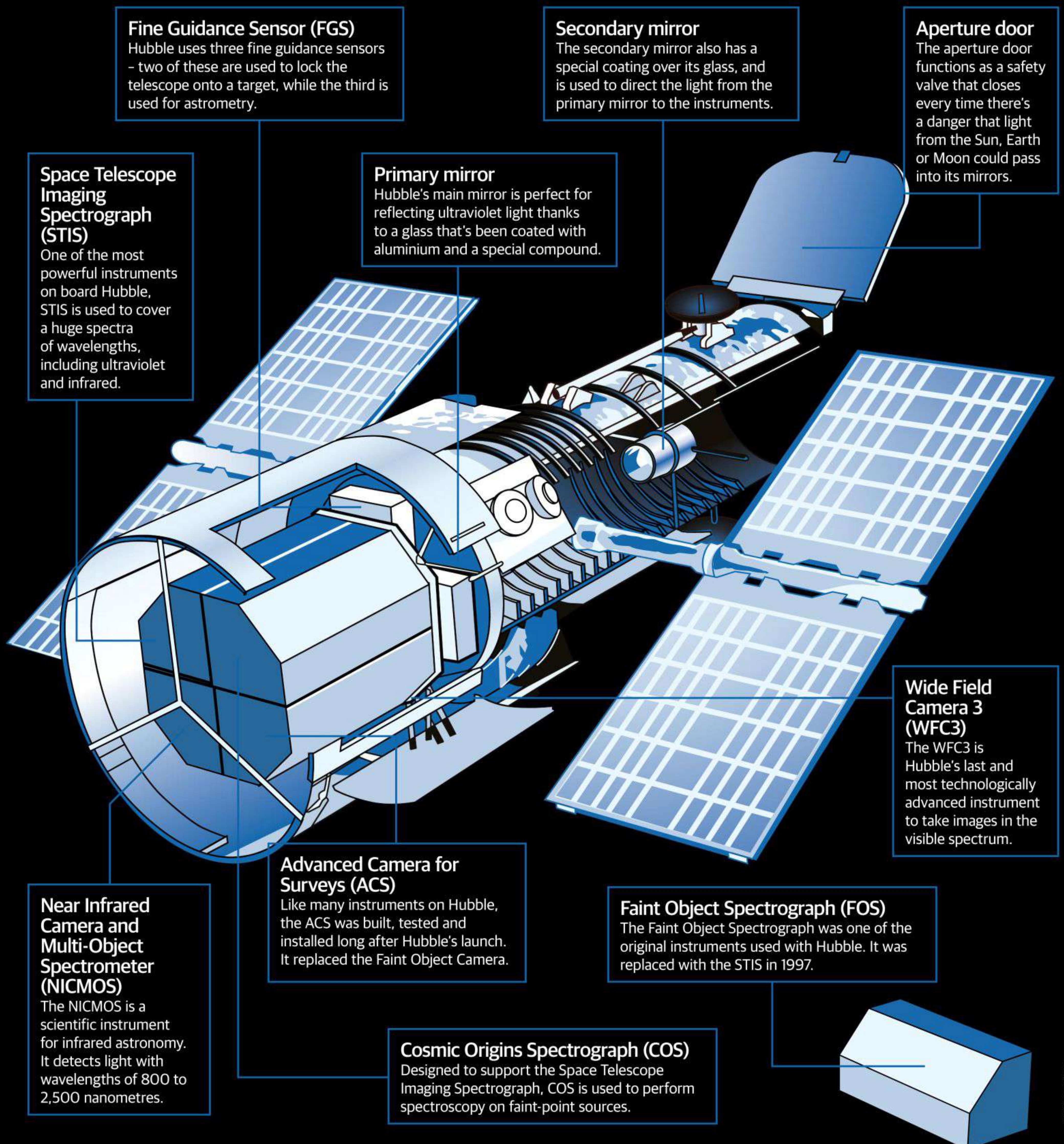
Hubble, named after the influential astronomer Edwin Hubble, was originally planned for takeoff in 1983, but when it slipped to a new deadline three years later the programme found itself placed on ice following the Space Shuttle Challenger disaster that killed its crew of seven. The tragedy rocked NASA to its core, but Hubble would eventually lift off from American soil aboard the Space Shuttle Discovery as the 20th century rolled into the 1990s.

Hubble began observations with five instruments to its name - the Wide Field and Planetary Camera (WFPC), Goddard High Resolution Spectrograph (GHRS), High Speed Photometer (HSP), Faint Object Camera (FOC) and the Faint Object Spectrograph (FOS). Each instrument consisted of contributions from NASA's entire breadth, ranging from the Jet Propulsion Laboratory to the Goddard Space Flight Center, and together they represented the most advanced technology the organisation could fit into one space-bound telescope.

But for all that funding and an incredible amount of workmanship and engineering, Hubble's initial images were actually blurred and out of focus. The reason? Its primary mirror had minute undulations around its edge which caused the light to bounce

Anatomy of the Hubble Space Telescope

The spacecraft's instruments have stood the test of time as it gazes deep into our Solar System and beyond



How to... service an observatory

Blasting off

In order to service Hubble, NASA launches a Space Shuttle via a pair of solid rocket boosters and an external tank. This would contain all the replacement parts and a mechanical arm.

off it in a way Hubble's ground control couldn't account for. It took over three years for NASA to remedy the problem, sending up its first service team to replace the telescope's main camera with a modified version. Suddenly Hubble could see clearly, and the results were astounding.

Over its long years of service, Hubble has dramatically changed how we see the wider universe. Through its instruments astronomers have been able to accurately measure stars with Cepheid variables - stars that pulse radially. Since such measurements were virtually impossible from terrestrial telescopes we're now able to determine the Hubble constant and understand just how fast the universe is expanding around us.

Thanks to its set of sensitive instruments and lenses, Hubble has also been able to shed more light on black holes and their relationships with the galaxies they reside within. Prior to Hubble, scientists theorised that black holes were common to some galaxies, but data collected by the space telescope has revealed it's more than likely most galaxies have black holes at their centre and that these cosmological anomalies share a deep connection with their homes, like our own black hole Sagittarius A*.

Operating the arm

Controlled via Mission Control and monitored by the astronauts themselves, NASA uses the Canadarm/Shuttle Remote Manipulator System (SRMS) to begin removing faulty components.

Heading for low-Earth orbit

The Space Shuttle, with a team of astronauts on board, breaks away from its boosters as it powers towards a low-Earth orbit with the components to service Hubble.

Installing new components

Over the course of around nine days, degraded or faulty elements are replaced by new and upgraded instruments and tools, enabling Hubble to continue its mission.

Returning to operation

After a period of 10 to 11 days, the Space Shuttle retracts the Canadarm and begins its short trip back to Earth. Hubble can now resume its stargazing vigil.

Hubble's legacy in astronomy even led it to discover the furthest known galaxy to date, GN-z11 - a high-redshift galaxy found in the constellation Ursa Major. The cosmic locale was observed in 2015 as it existed 13.4 billion years ago, which was around 400 million years after the Big Bang. The observation of GN-z11 is just one of countless discoveries Hubble has made, with over a million images already snapped since its cameras began operating optimally in 1993.

So what's next for Hubble? The observatory's orbit is slowly degrading, which is causing the telescope to drop in height over time. This has been corrected a number of times during the five service missions conducted by NASA, but it's clear Hubble's time in operation has a shelf life that's rapidly running out. Then there's the James Webb Space Telescope (JWST), which is still in development. With launch currently planned for March 2021 after being set back so many times, the JWST will serve as the observatory's spiritual successor.

NASA has yet to confirm how Hubble will eventually be decommissioned, but some of those involved in the programme have suggested it could be brought out of operation via a controlled deorbit and guided down into the ocean. However Hubble will be retired, it's clear that its impact on the future of astronomy will survive long after the observatory's demise.

TOP TECH

Wide Field Camera 3: Hubble's advanced eye

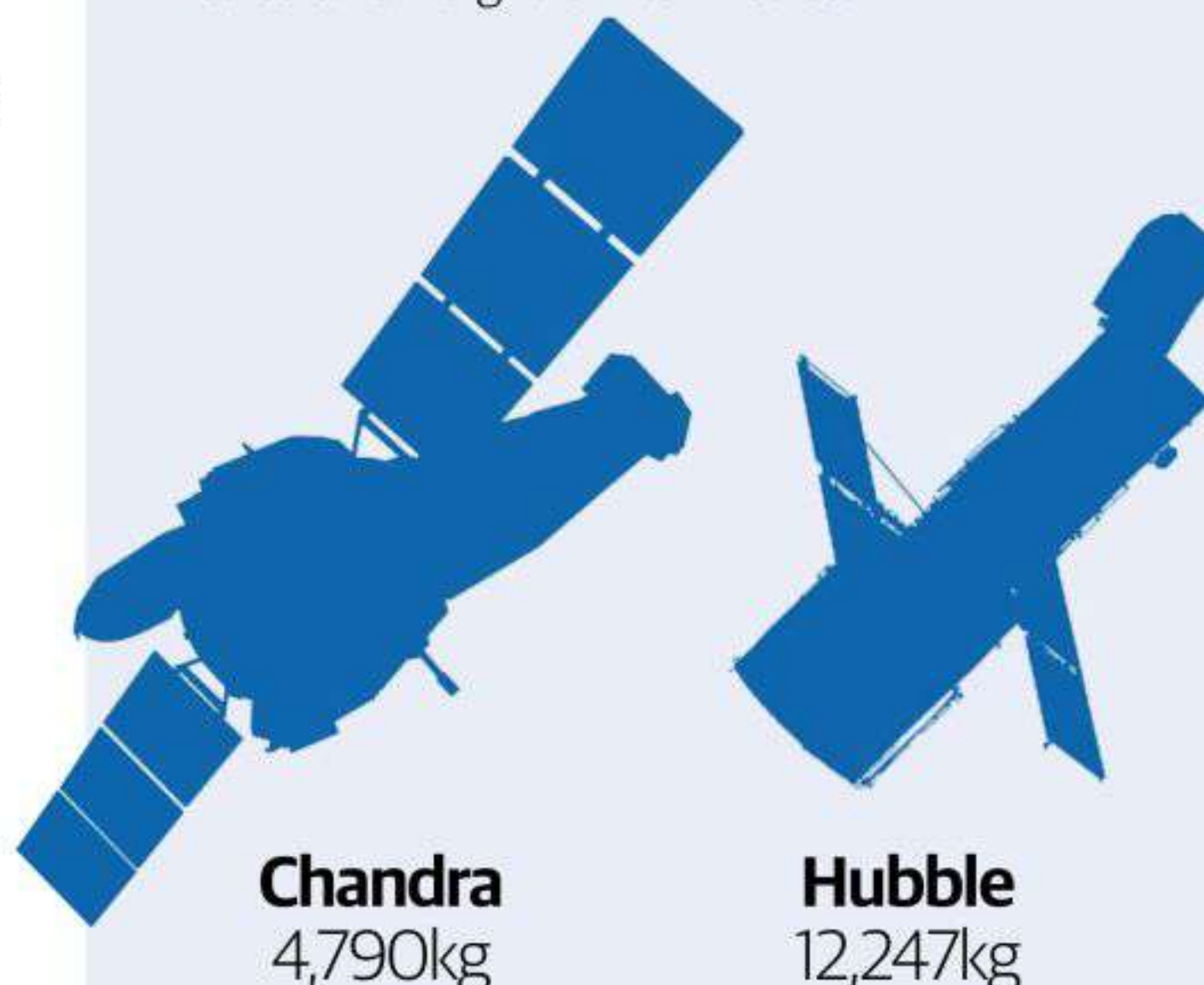
For years the most powerful lenses staring out into the cosmos were the Wide Field and Planetary Camera and Wide Field and Planetary Camera 2. As the years passed, one would replace the other, until 2009 when NASA installed what looks to be one of the last instruments to be added to the observatory before it's replaced by the James Webb Telescope. The WFC3 is still impressive, utilising two independent light paths: an optical channel that takes images from 200 to 1,000 nanometres and a near-infrared detector array that covers the wavelength range from 850 to 1,700 nanometres.



© NASA

Head-to-head Hubble vs Chandra

When it comes to weight, Hubble remains one of the chunkiest at 12,247 kilograms - 1,361 kilograms more than its original launch weight - noticeably heavier than the Chandra X-Ray Observatory which clocks in at 4,790 kilograms. In terms of sheer size, Hubble isn't quite as grand as the far newer Chandra, with its all-important measurements coming in at 13.3 metres by 4.2 metres compared to Chandra's larger 13.8 metres by 19.5 metres. Hubble and Chandra almost occupy the same space as a double decker with a length of 15 metres and height of 4.3 metres.



HOW TO...

Establish a space telescope

1 The big launch

Getting a large space telescope into space requires an incredibly powerful rocket to take it into low-Earth orbit. Since NASA was in the middle of its Space Shuttle Program in 1990, Hubble was launched inside Discovery.



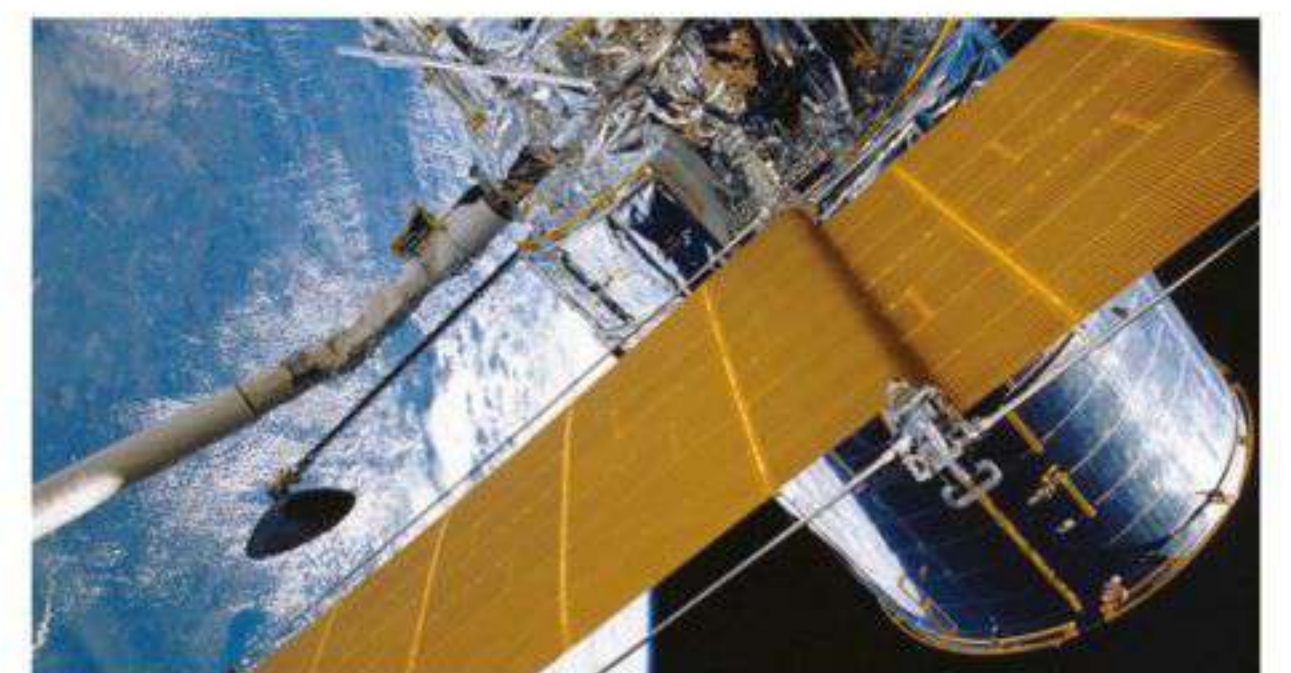
2 Reaching low-Earth orbit

To get Hubble into place, Discovery soared to a height of 600 kilometres (373 miles) above the Earth, separating itself from the three boosters. At this height, Discovery's crew of five is able to document the operation.



3 Unfurling the solar array

As the Hubble Space Telescope was removed from Discovery's cargo bay the remotely operated Canadarm robotic arm was unfurled. However, one Hubble's solar arrays refused to fully unfurl. An emergency spacewalk was prepped.



4 Launching Hubble into place

Following five days of operation - which included a number of experiments - the Hubble Space Telescope was tested and separated from Discovery. As began its long vigil above the Earth, Discovery and its crew returned home.



x4 © NASA/ESA/Hubble

Vital statistics

13.3

The length, in metres, of the Hubble Telescope



The length of a large US school bus

1,500,000

The number of observations Hubble has made since its launch in 1990

=

That's over 4,000 a month!

4 billion miles

The distance Hubble has orbited since 1990

=



Over 145,000 orbits of Earth

844GB

The amount of data that Hubble captures every month

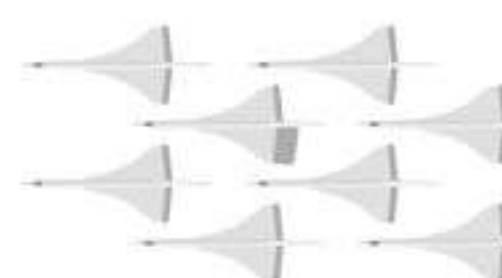
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That's almost 590,000 floppy disks!

17,500 mph

The speed of Hubble's orbit around the Earth

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13 Concorde

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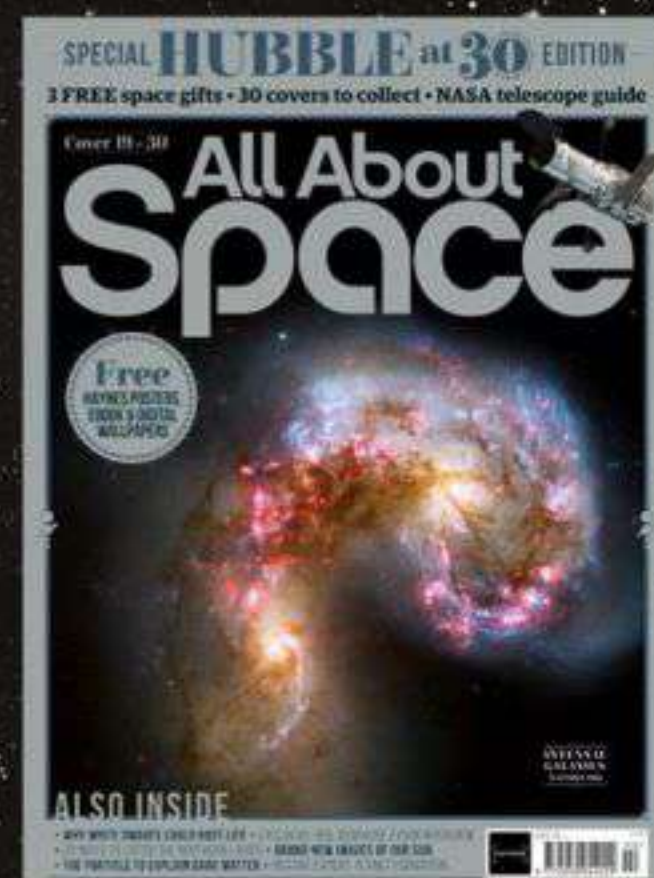
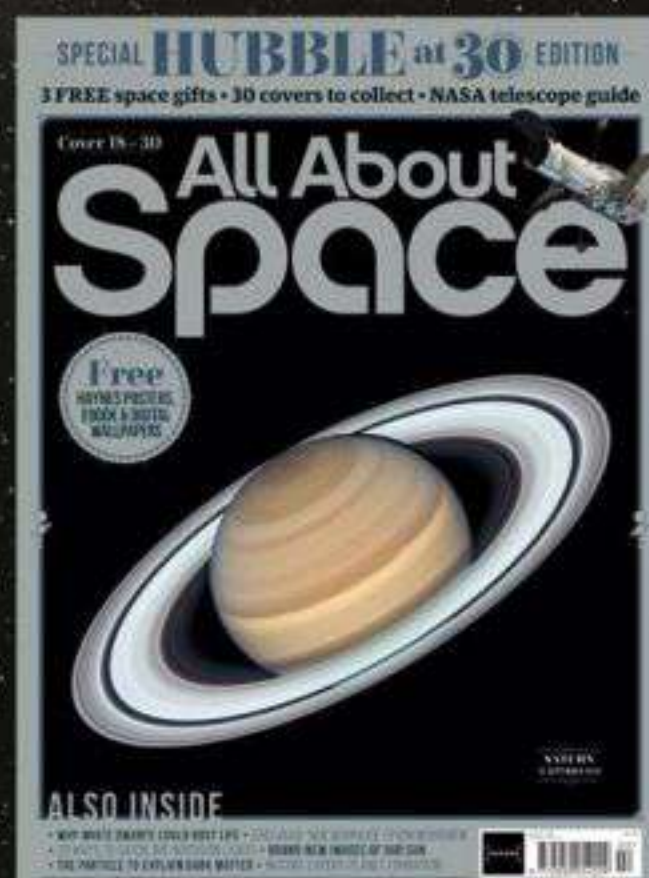
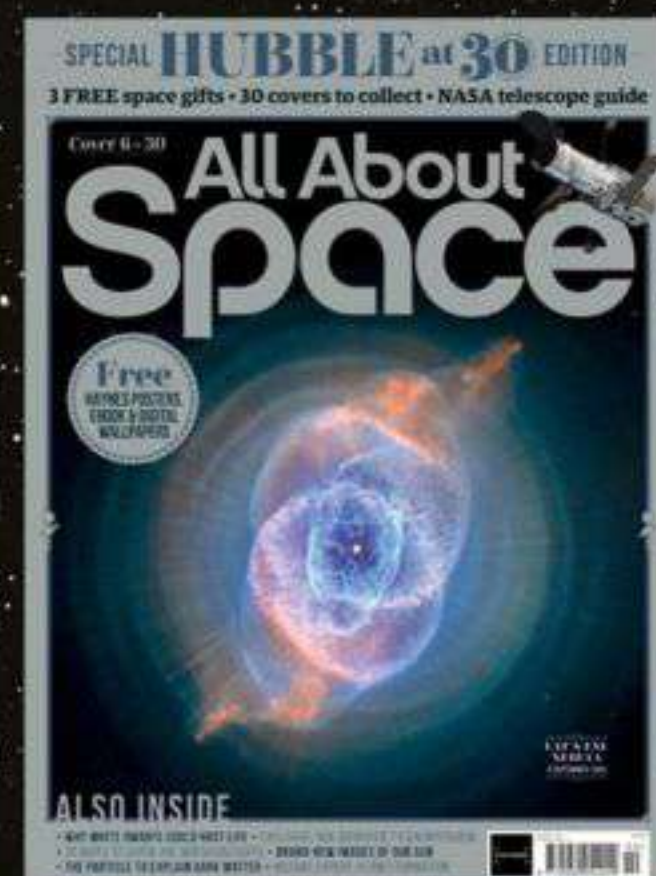
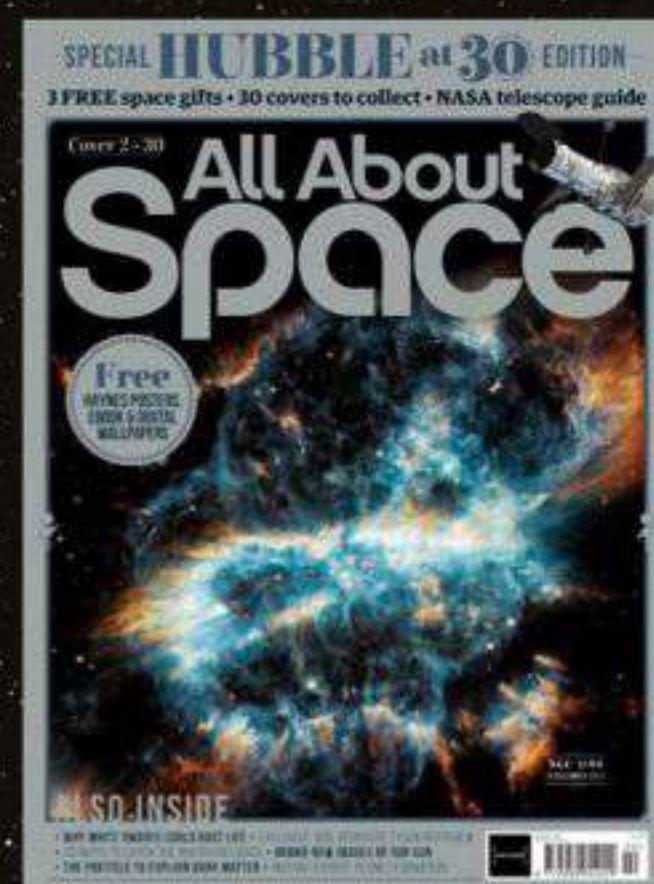
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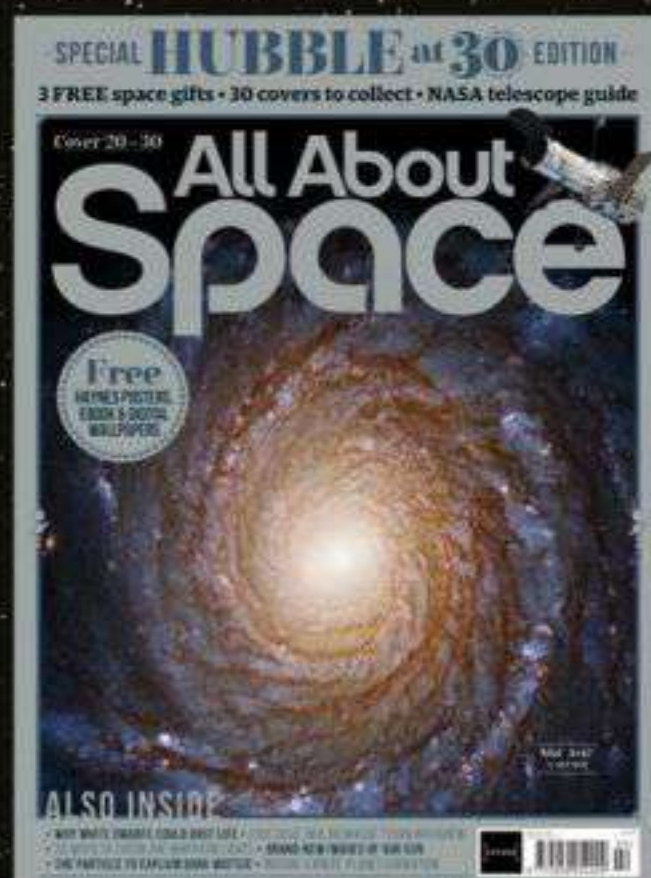


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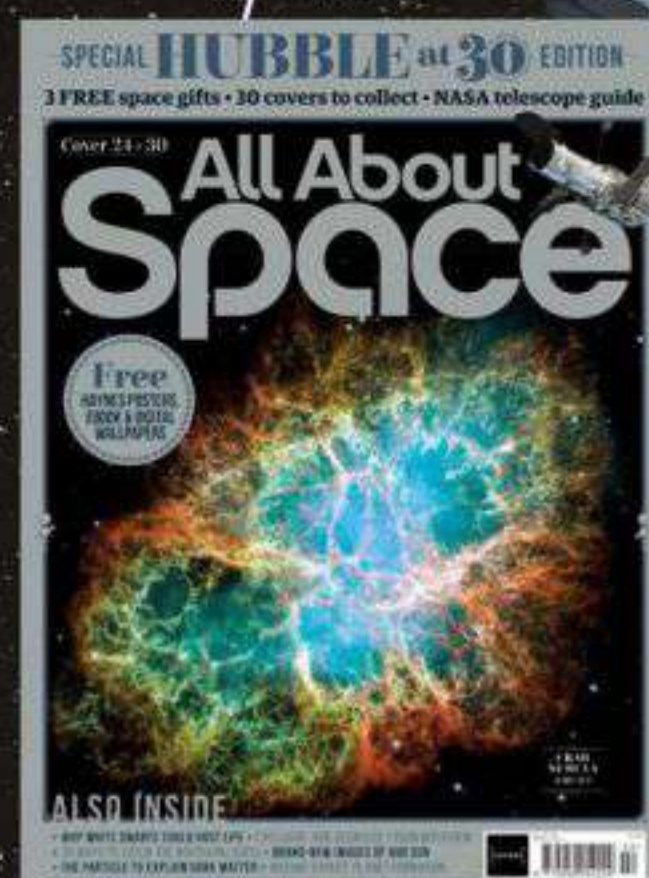
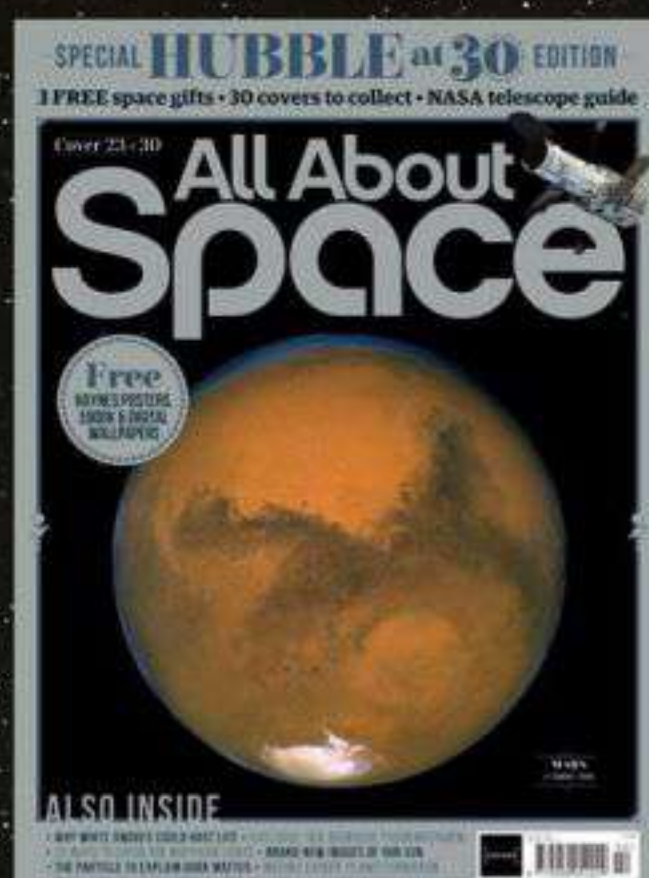
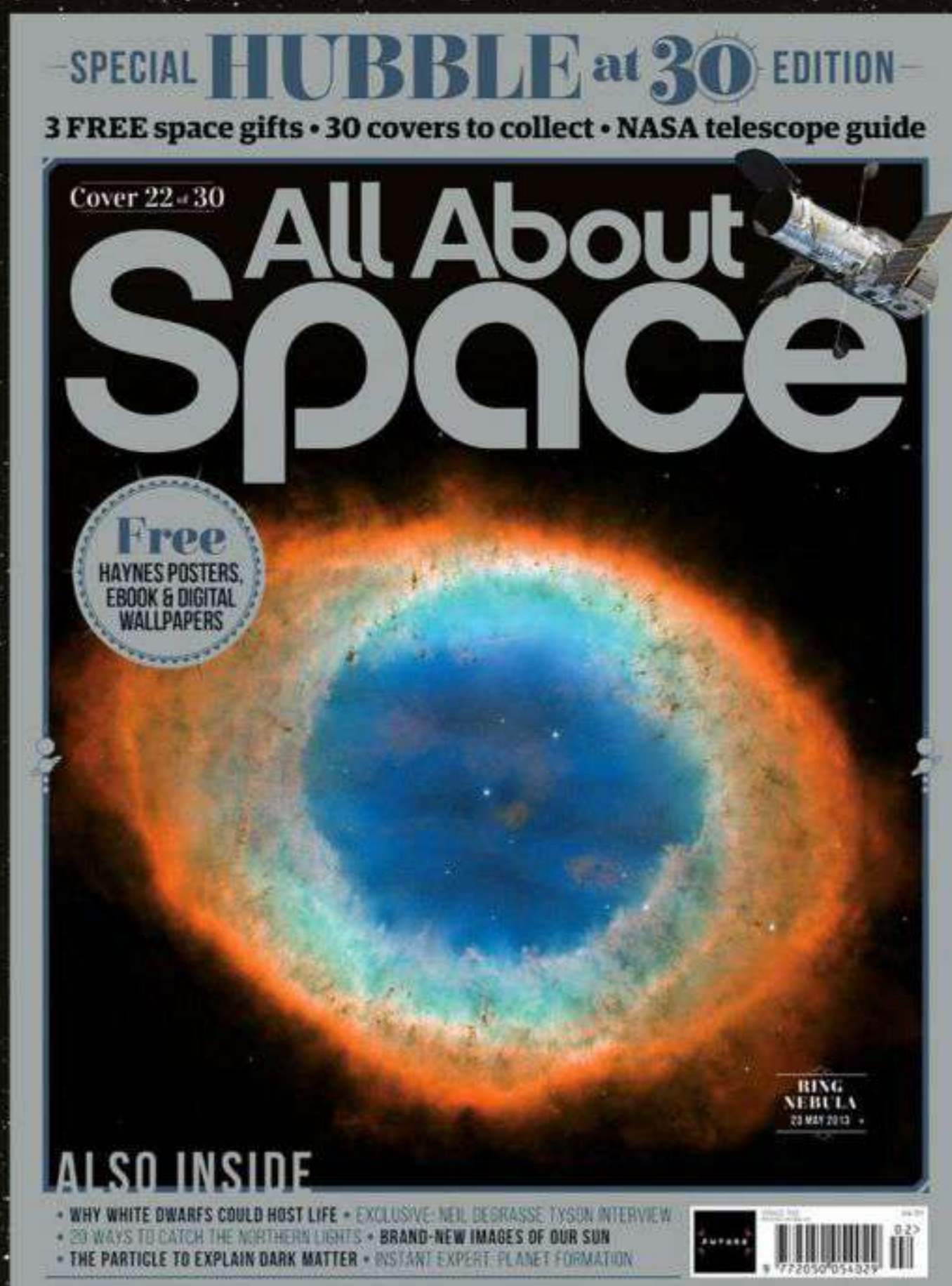


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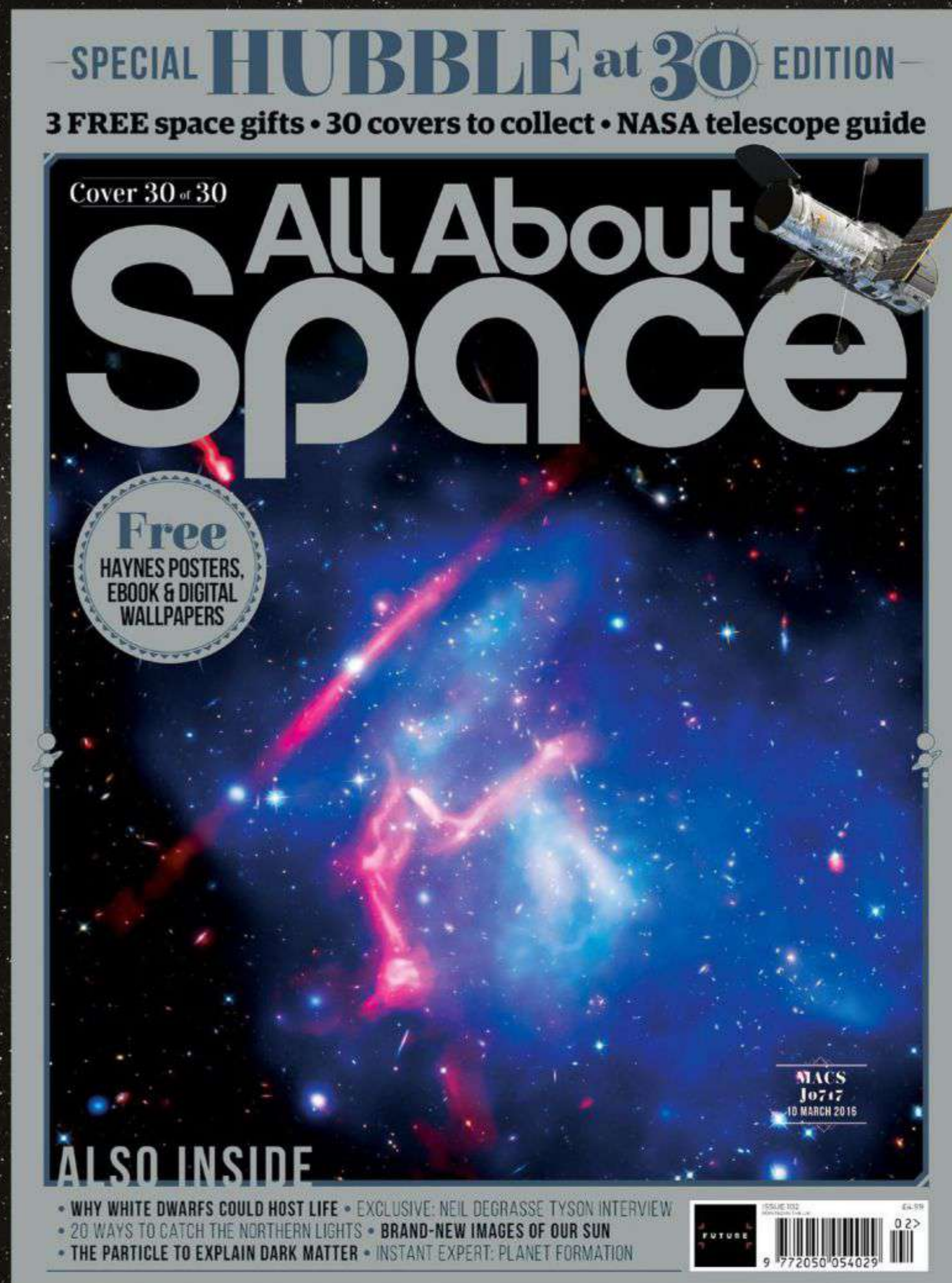


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WHITE DWARFS ARE THEY THE KEY TO LIFE?

New research suggests that we've been looking for other civilisations in all the wrong places

Reported by Colin Stuart

P

icture a planet that hosts life elsewhere in the universe. The kind where aliens wander around on its surface, going about their daily business much like you or I. What kind of planet comes to mind?

Normally the answer is one very much like the Earth because our planet sits in a temperature sweet spot. We're not too close to the Sun that we boil, nor too far that we freeze. Astronomers call it the Goldilocks zone because, like the porridge in the classic fairy tale, conditions are just right. Ideal for the all-important liquid water that is crucial to the existence of every life form on the planet.

For that reason much of our work to look for life beyond our Solar System has centred on the search for Goldilocks planets around stars like our Sun. Yet if recent research is anything to go by, we could be making a fairly sizeable mistake. "We could be missing a prime spot because of our own biases," says Paul Sutter of Stony Brook University in New York. Perhaps the best place to look for life is around dead stars.



White dwarfs

It's no secret that our Sun will eventually die. The hydrogen supply powering its energy creation will run out. After switching to burning helium instead, our star will bloat into a red giant, engulfing Mercury and Venus in the process. The Goldilocks zone will be pushed beyond our planet. "Earth will no longer be viable," says John Gertz, who sits on the boards of both SETI, the organisation behind the search for extraterrestrial intelligence, and Breakthrough Listen, a \$100 million (£77 million) initiative to scour the skies for signals from alien life. Any civilisation facing such a prospect will have to act or perish. Gertz attempts to 'get into E.T's mind' in a recent scientific paper published in the *Journal of the British Interplanetary Society*. His is an outsider's perspective. Although he studied medicine at university, he's not an astronomer or astrophysicist.

Instead he's an entrepreneur who runs a successful film production company in the movie heartlands of California. As a business person, he comes to the problem from an economic angle. What's the most cost-effective solution?

One option would be for the civilisation to escape their home system and journey across the wilderness of space to find another. That has to be weighed up against moving to a safer haven further out in their own system. Perhaps to a planet like Mars or even to the moons of a giant planet like Jupiter, both of which would get considerably warmer under the increased glare of the dying star. But even that is not an easy path. "We're talking about a Solar System in great distress," Gertz says. The solar wind - the breeze of charged particles howling away from the Sun and other stars - becomes a hurricane. Solar flares get

more frequent and intense. According to a recent study led by Dimitri Veras at the University of Warwick, this will have a knock-on effect on the asteroid belt too. "The increased solar luminosity will easily spin up the asteroids to break-up speed. As a result, the main belt of asteroids will likely be pulverised into an extended debris field," Veras says. Dangers upon more dangers. "No place within the Solar System will be safe from the threat of asteroid bombardment."

Despite these existential threats, moving to another solar system is a huge undertaking. "It's like moving to another country, whereas moving elsewhere in the Solar System is like changing bedrooms," says Sutter. Gertz thinks it's just too difficult, too economically expensive. "It's not going to happen," he says. Even if some of the inhabitants of the stricken planet do manage to

HOW STELLAR CORPSES ARE MADE

3 Planetary nebula

Helium burning is unstable, and eventually the star sheds its outer layers into space.

2 Red giant

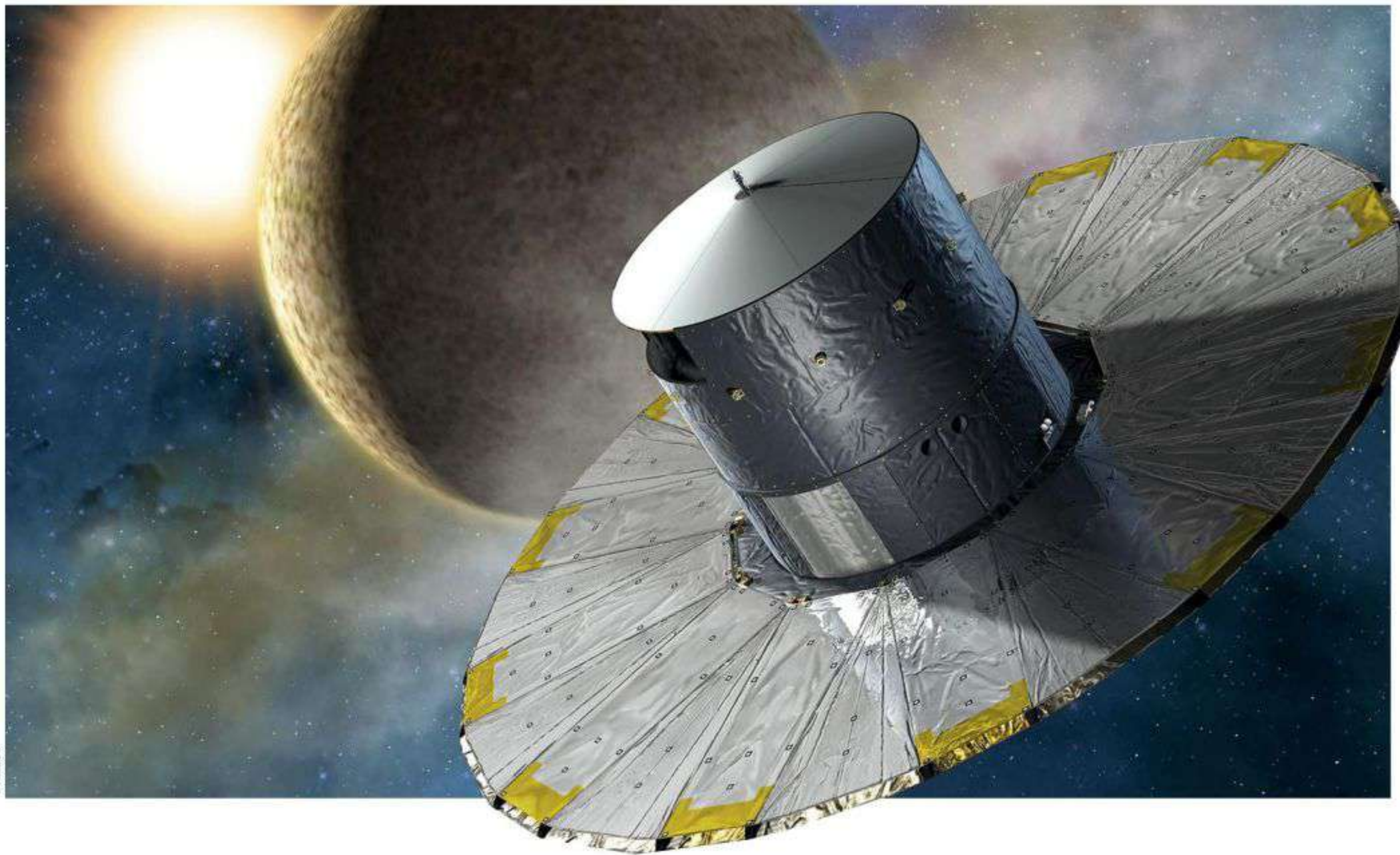
Once hydrogen burning stops and helium burning starts, the star bloats.

1 Main sequence

A star burns hydrogen during this phase, which lasts most of its life.

4 White dwarf

A core of carbon and oxygen - the products of helium burning - is left behind.



© ESA

escape, they won't be able to evacuate everyone, so the majority of the civilisation is stuck where it is, battling to save itself against the ravages of a star in the twilight of its days. If a civilisation is already facing the death of its star, it has to be one of the oldest stars in the universe. That life would likely have been there a long time, arguably with the most mature technology of any species in the cosmos. "Major astral engineering would be required to survive, and that might be detectable," says Gertz. They may also be sending out distress signals in a last-ditch attempt at salvation. We may also have a better chance of hearing their mayday. Without as much background noise, "trying to be heard might be easier than around a normal star," says Sutter.

If their efforts are ultimately successful, they'll find themselves orbiting a white dwarf star. When stars like the Sun die they shed their outer layers into space to form a shell called a planetary nebula. At its heart is a white dwarf, an ever-cooling core of carbon and oxygen, by-products of the helium burning that saw the dying star bloat in the first place. A white dwarf is about the same size as Earth, whereas the original star was around a million times bigger. So far they've been largely overlooked as a place to search for life, but while they are small in stature they are not in number. White dwarfs account for 15 per cent of all the stars in the universe, and their ranks are only set to swell. "95 per cent of stars will become white dwarfs," says Thea Kozakis, a PhD student at the Carl Sagan Institute, part of Cornell University.

Kozakis' work is focused on modelling the atmospheres of planets around white dwarfs. "A planet could stay in the habitable zone of a white

Above: Gaia has revolutionised our understanding of white dwarfs by finding so many of them

Below: As the Sun brightens and bloats, Mars could become a more habitable planet for us

The crust

This outer layer is thought to be about 50 kilometres (31 miles) thick.

A super-thin atmosphere

Some hydrogen and helium remains trapped in the white dwarf's gravity.

Compact crystals

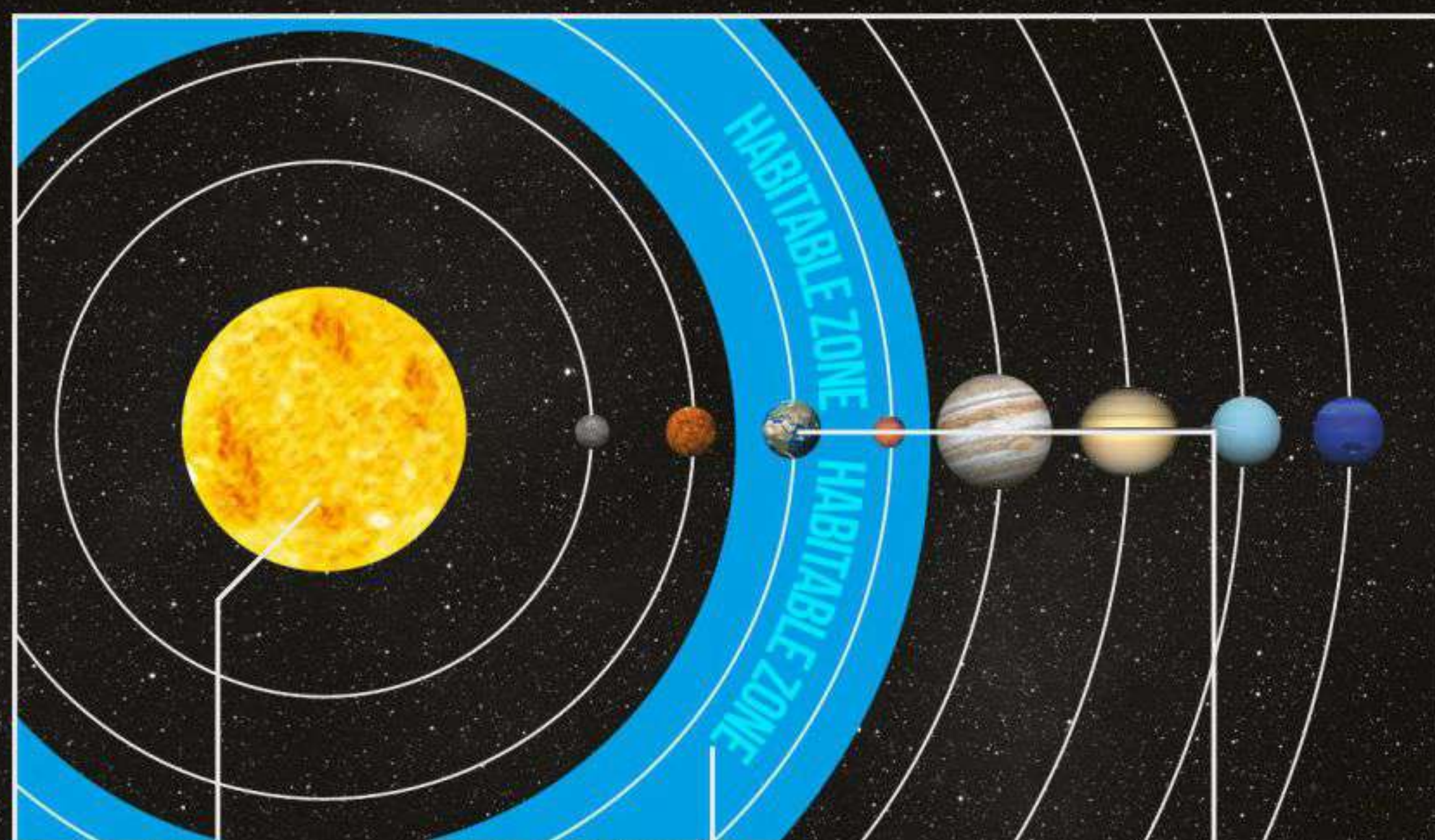
As the white dwarf cools, the carbon in the core settles into crystal structures.



Source: Wikipedia commons © Daein Ballard

SHIFTING HABITABLE ZONES

CURRENT



4.5 BILLION YEARS AGO A new star

The newly formed Sun was much cooler than today, so the habitable zone would have been closer in.

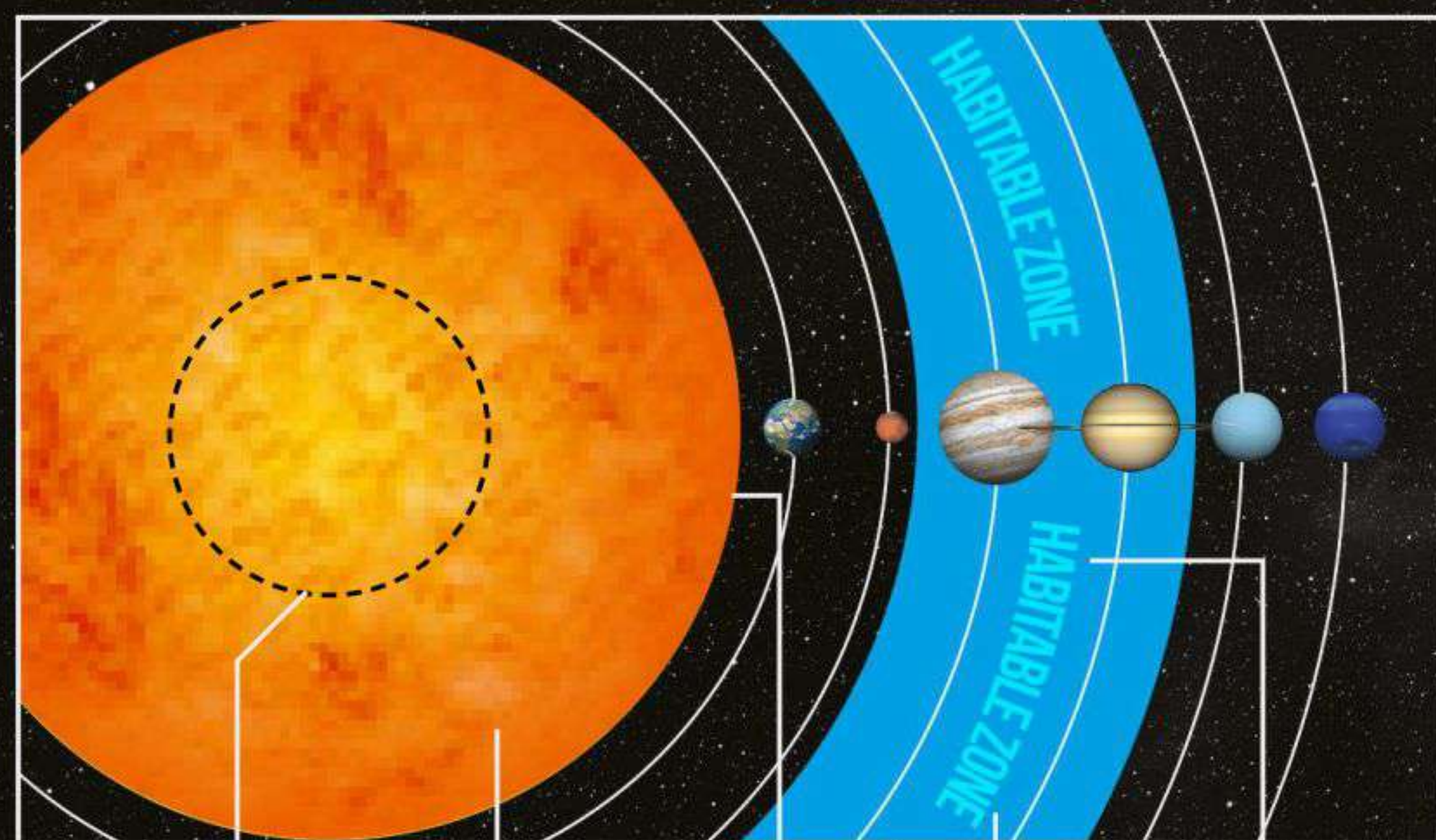
3 BILLION YEARS AGO Mars habitable?

The Sun warms over time, pushing the habitable zone out. A time when Mars may have been habitable.

NOW Current climate

Earth is the only planet completely in the habitable zone of the Sun, with temperatures right for liquid water.

FUTURE



1.5 BILLION YEARS FROM NOW Death knell

The Sun will be 15 per cent brighter than it is today, pushing the habitable zone beyond the Earth.

10 BILLION YEARS FROM NOW White dwarf

Around a much cooler host, the habitable zone will be 100-times closer than it is today.

20 BILLION YEARS FROM NOW The end

With insufficient heat, there will no longer be a habitable zone around what was once the Sun.

5 BILLION YEARS FROM NOW Red giant

The dying Sun will begin to expand as it starts to burn helium, swallowing Mercury, Venus and possibly even the Earth.

13 BILLION YEARS FROM NOW Cooling crisis

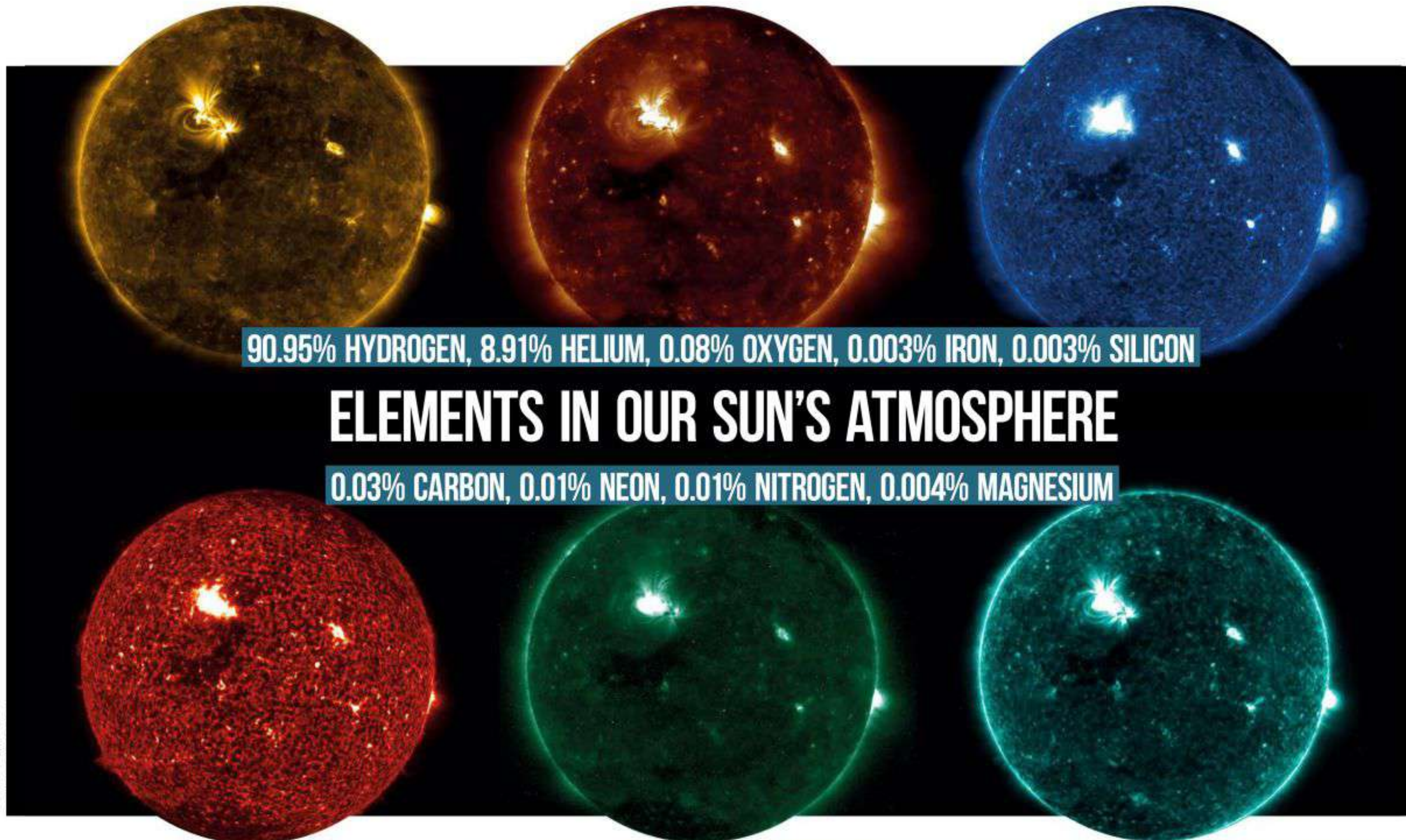
As the white dwarf cools, the habitable zone gets tighter and tighter, leading to planets experiencing greater tidal forces.

dwarf longer than it could with the Sun," she says. "It's actually a pretty stable environment." We're talking about a habitable zone lasting 8.5 billion years. That could make it an ideal destination for an otherwise doomed species that could overcome the significant obstacles of moving solar systems. You certainly wouldn't have to worry about the death of your star - it's already happened. Yet Kozakis is more interested in life that emerges only after the star has transitioned into a white dwarf.

A rocky planet that initially had its atmosphere stripped away could regain one as it's pummelled by an increase in asteroid and comet activity. We already suspect such events delivered much of the water to the early Earth before life rapidly took hold. What happened here could happen there too. We already see evidence of material heading inwards and falling on white dwarf stars. "A lot of useful material is being transported towards where the habitable zone would be," says Kozakis.

Not everything would be the same though. A white dwarf is hot, but its diminutive size means it struggles to emit its heat through such a limited surface area. Consequently, the habitable zone is a hundred-times closer than the Sun's as you need to huddle closer to get the same warmth. A potentially habitable planet would orbit the white dwarf in a matter of days. "That can lead to tidal disruption," says Kozakis. This is where the difference in gravity felt between the two sides of an orbiting object leads to deformation. Like the constant squeezing of a squash ball, this injects extra energy into the planet's interior. This already happens in several places in our own Solar System, most notably on Jupiter's moon Io, where it results in intense volcanism. That's hardly conducive to a life-friendly world. "Planets around white dwarfs can avoid this if their orbit is very circular," says Kozakis. That orbital path must deviate from a circle by less than one part in a million. If that sounds like an unlikely scenario, it may not be. "Planets that migrate inwards towards a star do tend to end up on circular orbits," Kozakis says.

While a tight orbit puts any life under unusual strain, it should make such planets easier to find. One of the techniques we use to detect planets beyond our Solar System is called the 'transit method'. As a planet orbits, it can periodically pass between us and its star, causing the star to dim. This is how the Kepler space telescope found thousands of alien worlds. Yet for small Earth-like planets around big Sun-like stars, the drop in brightness is typically 0.01 per cent. Teasing these changes out of the background variation of the star can be a real challenge. "It may be easier with white dwarfs," says Kozakis. The small size of the dead star means that a transiting planet would block around 50 per cent of the star's light - a much more obvious effect. Normally to confirm the presence of a planet, astronomers wait for three equally spaced transits to make sure that the



ELEMENTS IN OUR SUN'S ATMOSPHERE

90.95% HYDROGEN, 8.91% HELIUM, 0.08% OXYGEN, 0.003% IRON, 0.003% SILICON
0.03% CARBON, 0.01% NEON, 0.01% NITROGEN, 0.004% MAGNESIUM

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© NASA

change in brightness really is down to an orbiting world. For an Earth-like planet you'd have to wait three years. Yet habitable planets around white dwarfs would go round in a day or two. You could see the three transits you need in a week. That said, you still need to be keen-eyed. "Each transit only lasts a minute," says Kozakis. Hubble and the upcoming James Webb Space Telescope (JWST) should be up to the job. The Transiting Exoplanet Survey Satellite (TESS), launched in April 2018, can also join the search party.

It's a great time to be contemplating life around white dwarfs. In 2013 the European Space Agency launched Gaia to chart the positions and distances of a billion stars in our Milky Way. Before 2018 only 30,000 white dwarfs had been discovered. Now, thanks to the last haul from Gaia, it's over 250,000. For the first time we're getting a concrete census of these enigmatic objects. We're also understanding how they change over time. Without a source of new heat, a white dwarf gradually cools, and the habitable zone shifts with it. An effect called white dwarf crystallisation was predicted as far back as the 1960s. As the carbon and oxygen cool, it condenses into a crystal structure. Yet this

wasn't confirmed until 2019. Understanding the way a white dwarf's energy output changes as it crystallises could tell us more about how long life is able to stick around in its presence.

With all these factors considered, Kozakis says that people are starting to wake up to the idea of life around white dwarfs and are beginning to look for signs of life there. Over the past three years tentative SETI searches have also sought out signals coming from these systems. If we're serious about finding life elsewhere in the universe – arguably the biggest discovery in all of human history – then we need to keep our options open. That means looking in all the places that aliens could be hiding, not just those most similar to us. As Sutter says: "It's worth a shot."

"A PLANET COULD STAY IN THE HABITABLE ZONE OF A WHITE DWARF LONGER THAN IT COULD WITH THE SUN. IT'S PRETTY STABLE" **THEA KOZAKIS**

Above left: An example of a Sun-like star shedding its outer layers as it approaches the end

Above right: The Transiting Exoplanet Survey Satellite (TESS) being prepared prior to its launch in 2018

POSSIBLE CANDIDATES

The nearer the white dwarf, the easier it is to look for signs of life

SIRIUS B
8.6 LIGHT YEARS



© NASA/ESA

PROCYON B
11.46 LIGHT YEARS



© NASA/ESA

VAN MAANEN'S STAR
14.04 LIGHT YEARS



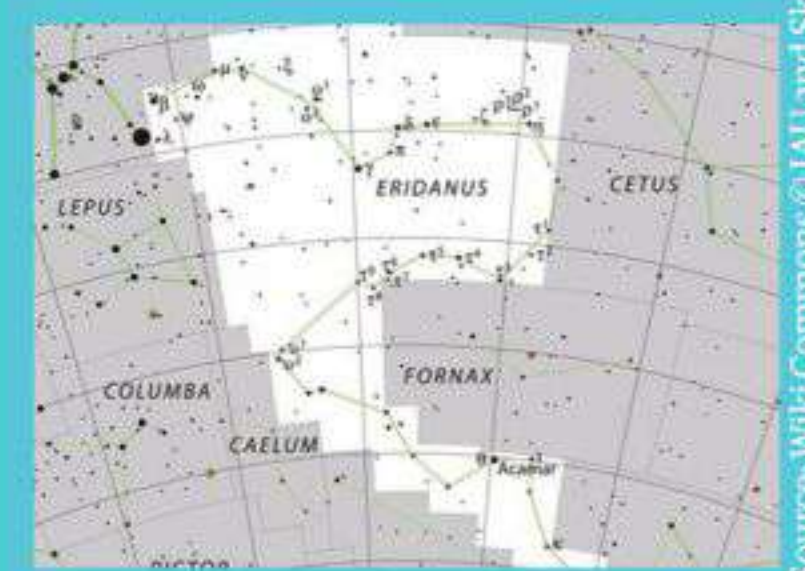
Source: Wiki Commons © Sephirothq

GJ 440
15.11 LIGHT YEARS



Source: Wiki Commons © IAU and Sky & Telescope magazine

40 ERIDANI B
16.26 LIGHT YEARS



SHAPESHIFTING SPACECRAFT

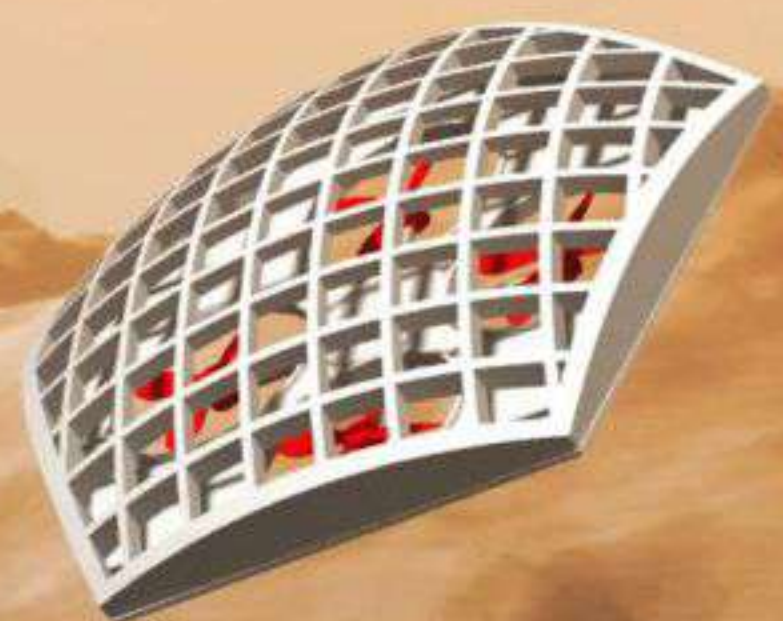
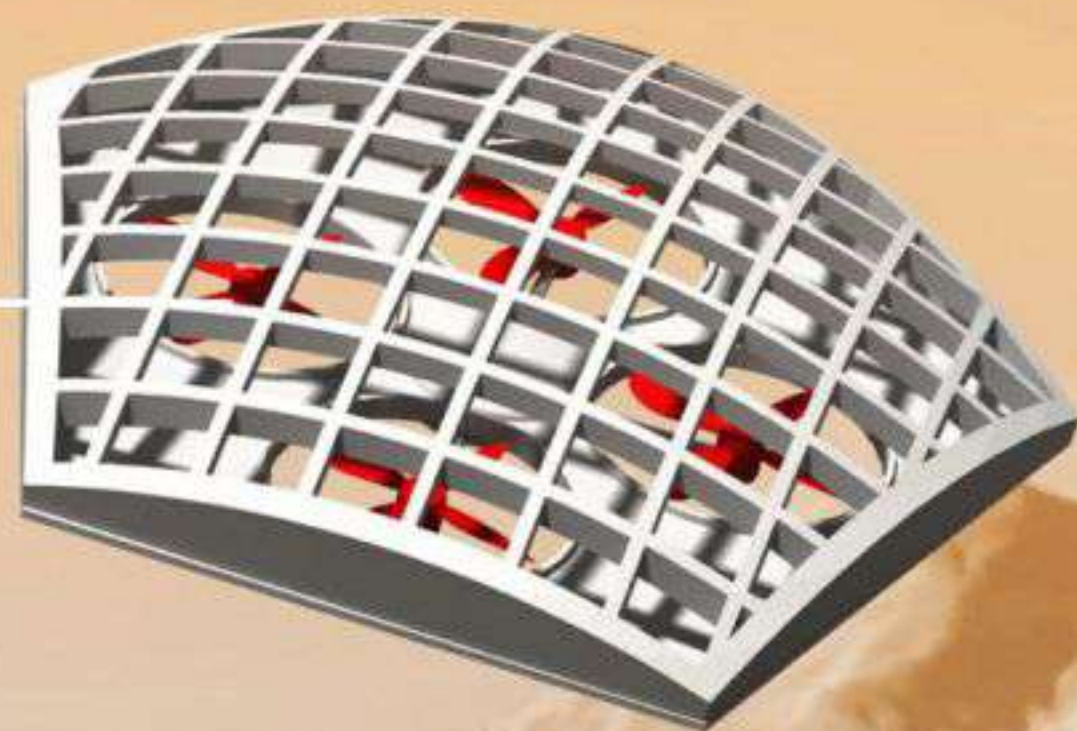
Futuristic robotic explorers could seamlessly switch between swimming and spelunking

A team of scientists and engineers at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, are devising a concept mission which could see a swarm of mini-robots exploring worlds beyond our own - and top of the list is Saturn's moon Titan. This swarm will be like no other mission before it, as it will consist of a team of up to 12 robots that can morph into different shapes that can help them roll, fly, float and swim. These robots have appropriately been named 'Shapeshifters'.

When NASA's Cassini mission flew past Titan and dropped the European Space Agency's Huygens probe onto the surface, it revealed a world of lakes, rivers and oceans - flowing with liquid ethane and methane instead of water - as well as volcanoes spewing out ammonia and water, also known as 'cryovolcanoes'. Earth also exhibits oceans, volcanoes and other features carved out by liquids, as well as ethane and methane. This resemblance between Titan and Earth has scientists itching to return to the Saturn moon to explore further.

Sticking to formation

When the Shapeshifters explore caves - called spelunking - they can form a chain to maintain communication with the surface.



The transporter

This robotic team will also be used to transport large and heavy objects, including the Shapeshifter's 'mothership' lander.

Stop, pop and roll

When on the surface the Shapeshifter will pop out into a ball, which will then roll across the surface in a way to conserve energy.



The NASA Innovative Advanced Concepts (NIAC) Program provides an important platform for creative ideas to come to life. In this case, the project has allowed scientists at JPL to scrutinise the idea of exploring Titan in a truly original way. By exploiting the moon's thick atmosphere and low gravity, flying is the favourable mode of transport. But what if you don't have to be restricted to flying?

JPL principal investigator Ali Agha and colleagues at Stanford and Cornell universities are envisaging a swarm of mini-robots - called 'cobots' - that can float around in Titan's hydrocarbon lakes, morph into a ball so they can roll across the surface and can morph once again into a drone, where propellers will send it gliding through the atmosphere.

"We have very limited information about the composition of the surface: rocky terrain, methane lakes, cryovolcanoes - we potentially

have all of these, but we don't know for certain," said Agha. "So we thought about how to create a system that is versatile and capable of traversing different types of terrain but also compact enough to launch on a rocket."

The Shapeshifter swarm will arrive at the moon on board the 'mothership'. Similar to the Huygens probe, the mothership will touch down with the help of a parachute, carrying a scientific instrumental suite to provide an in-depth analysis of the surface. At the same time it will provide an important pit stop for the cobots as an energy source. The cobots will return the favour by transporting the mothership via the medium of flight. Agha predicts that it would take about ten cobots to move the mothership.

In terms of production, the Shapeshifter concept mission is very much in the early stages. Engineers at JPL have created prototypes that are being used to demonstrate the feasibility of

semi-autonomous robots capable of morphing. A 3D-printed prototype that is currently being used to explore the backyard of JPL is essentially a drone caught inside a hamster wheel - it has propellers encased within two halves of a wheel. After splitting into their respective halves, the drones could then transition from surface-rolling into aerial exploration.

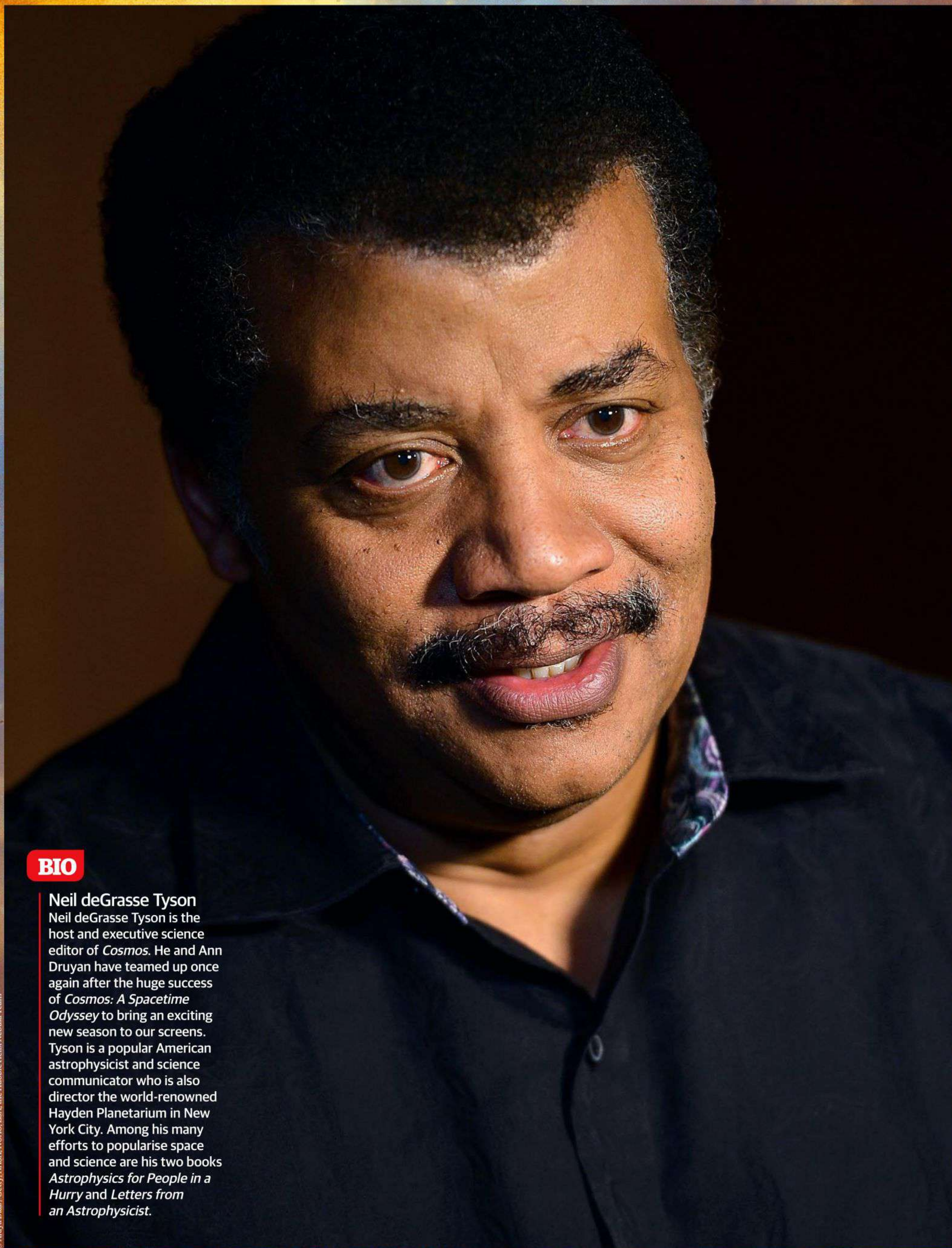
The engine

Each cobot is fitted with propellers, providing them with the movement that will take them swimming, flying or rolling.

Torpedo shape

In order to swim through liquids on other planets, the cobots will take a torpedo-like shape. This will allow for a more efficient mode of under-liquid movement.





BIO

Neil deGrasse Tyson

Neil deGrasse Tyson is the host and executive science editor of *Cosmos*. He and Ann Druyan have teamed up once again after the huge success of *Cosmos: A Spacetime Odyssey* to bring an exciting new season to our screens. Tyson is a popular American astrophysicist and science communicator who is also director the world-renowned Hayden Planetarium in New York City. Among his many efforts to popularise space and science are his two books *Astrophysics for People in a Hurry* and *Letters from an Astrophysicist*.

NAT GEO EXCLUSIVE: PART ONE

NEIL DEGRASSE TYSON TALKS COSMOS POSSIBLE WORLDS

With a new series of *Cosmos* hitting our screens, **All About Space** catches up with the astrophysicist to talk about the show, the science and Carl Sagan

Reported by Lee Cavendish

One thing you mention in the new series is “the scientific myth about the origins of life”. Can you explain the phrase, because it sounds like an internally disruptive scientific method?

A myth used in that context is a story that gathers together our collective understanding of what has happened. Unfortunately the word ‘myth’ has become synonymous with ‘false’. Is it true or is it a myth? Well, a myth is a story. You can stitch together anything to make a story, and it rises to a level of epic significance.

We all know the myths of Odysseus and the journey that he took. You’re not saying, “Oh, the story is false.” That’s not how you’re thinking about the story. You’re thinking about it as an important communication of ideas. But you picked up on that [in the show]. These are objectively established truths that, where we use the word myth, Ann felt strongly about the word ‘myth’ in that context at the time we were doing it. She convinced

me that in its usage in that context, that was a way to get you to recognise what role science is playing and bringing an understanding to it.

You had a run in with Carl Sagan in your younger years. What was that experience like and how does it feel now to be doing his job on *Cosmos*?

We told the story in *Cosmos* [*A Spacetime Odyssey*] from 2014. When I first met him, I was 17 years old. I was in high school, and he invited me to visit the campus where he taught to help me decide whether I would choose that institution.

What we didn’t say in the show is that I didn’t attend. I went to a different school. We left that out. [Laughs]. But I had what I thought were rational reasons for not going. Were I to go, it would have been because of him. But I knew, even in high school, that professors can change institutions. Maybe if I go there because of him

Interview Neil deGrasse Tyson

and then he moves, then I'm there and he's not there. The institution I chose to go to had a much larger faculty of astrophysicists there, so I wasn't chasing just one person. That's why I didn't go.

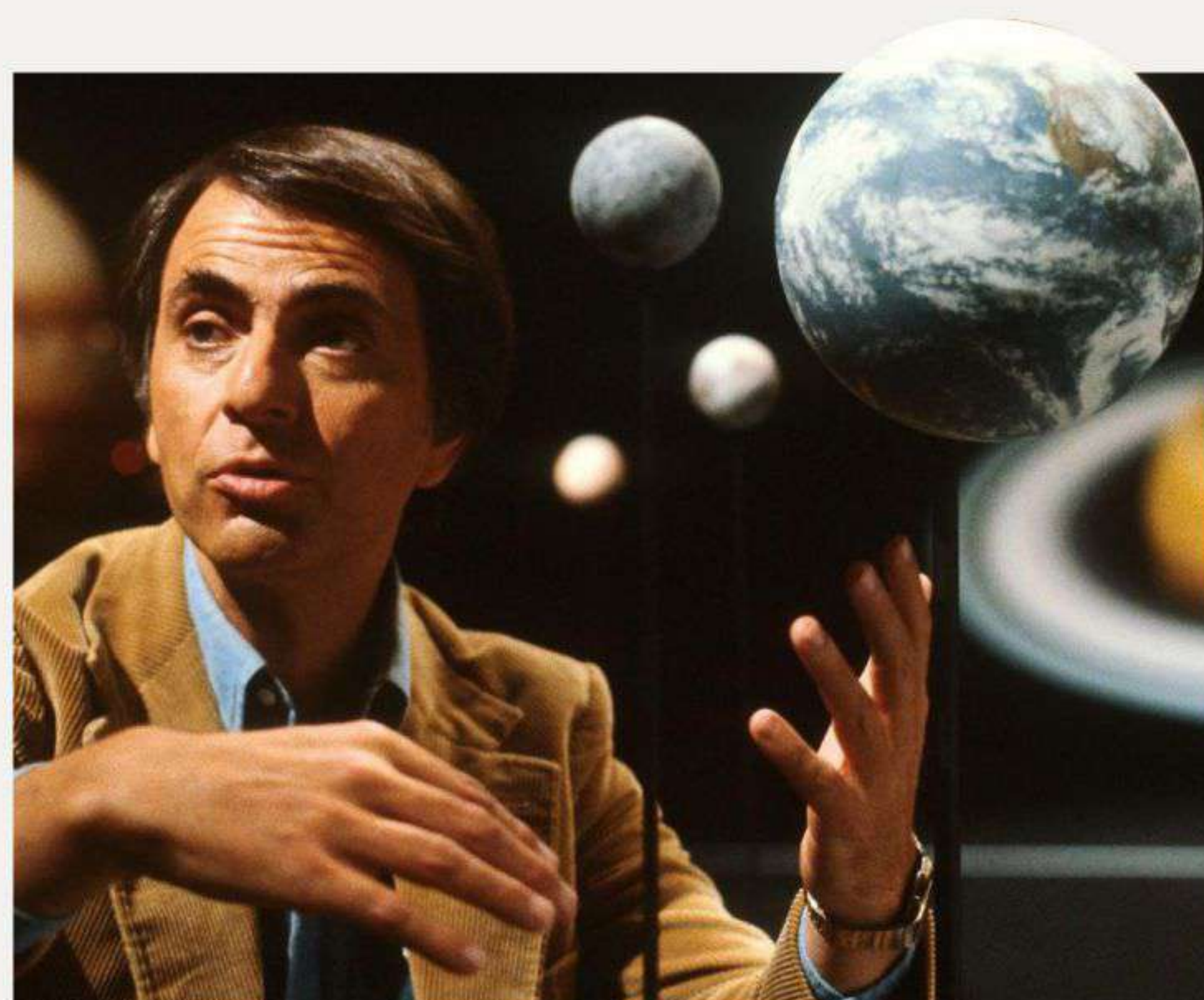
But what affected me was the attention he gave me. Someone he had never met. Someone who he knew was interested in the universe, because I was interested from age nine, and now I'm 17, so it's half of my life. I thought to myself, if ever there's a student who needs my attention as guidance for what their future paths will be, I will make time for them. And so that really imparted within me a sense of duty and responsibility to keep the wheel turning, because science is an epic transfer of discovery of one generation into the foundations for the next generation, who then go and make the next round of discoveries.

You often appear as yourself in Hollywood movies and TV shows. Please tell us a bit about how you end up saying 'yes' to these opportunities?

I have a very soft spot for when I am asked to help or participate in the project of an Artist - I use 'Artist' with a capital A, so that would be a painter, sculptor, a novelist, a screenwriter or set designer. If they call me up and say we want to add a little bit of science to this project, I'm there, because if science infuses art, it is a force that helps mainstream science.

We all know about art. Art has been the foundation of cultures for thousands of years. Why do Americans visit Europe if not to absorb the art that is in the streets, which are taken for granted? We don't have that in the United States. We come for the art. If there's science in it, then I help them out. And so, generally, I'm playing myself as a scientist.

There's another case. I don't mean to brag, but I had a cameo appearance in *Sharknado 6*. [Laughs]. I was overlooked by the Academy. But I play Merlin. And I'm doing science, but people think it's magic.



© Alamy

"I DON'T MEAN TO BRAG, BUT I HAD A CAMEO APPEARANCE IN *SHARKNADO 6*"

NEIL DEGRASSE TYSON

What do you have to say about Pluto's demotion?

Get over it. [Laughs]. Pluto is happier where it is. It is among other objects that resemble it in its orbit, in its material, in its construction, and so it's found a new home. Instead of being the puniest planet, it is one of the biggest of the icy bodies in what we call the 'Kuiper Belt' in the outer Solar System. Pluto wasn't the ninth planet discovered, it was the first of the Kuiper Belt discovered; we just didn't know that.

What is the future of *Cosmos*? Are there going to be new seasons and do you have ideas for that?

When we did the 2014 season, I don't think we had the concept of 'new season' in our head. It was more, "We need to do *Cosmos* again. It's been 34 years, from 1980 to 2014." And not that I know this firsthand, but I imagine it's like giving birth.

Okay, there's so much of you that goes into it and so much stress, so much energy and so much money into all of it. And I remember soon after we finished that people said, "When is the next season coming?" Do you go up to a woman who just gave birth and say, "Are you going to have another kid right now?" It's the wrong time.

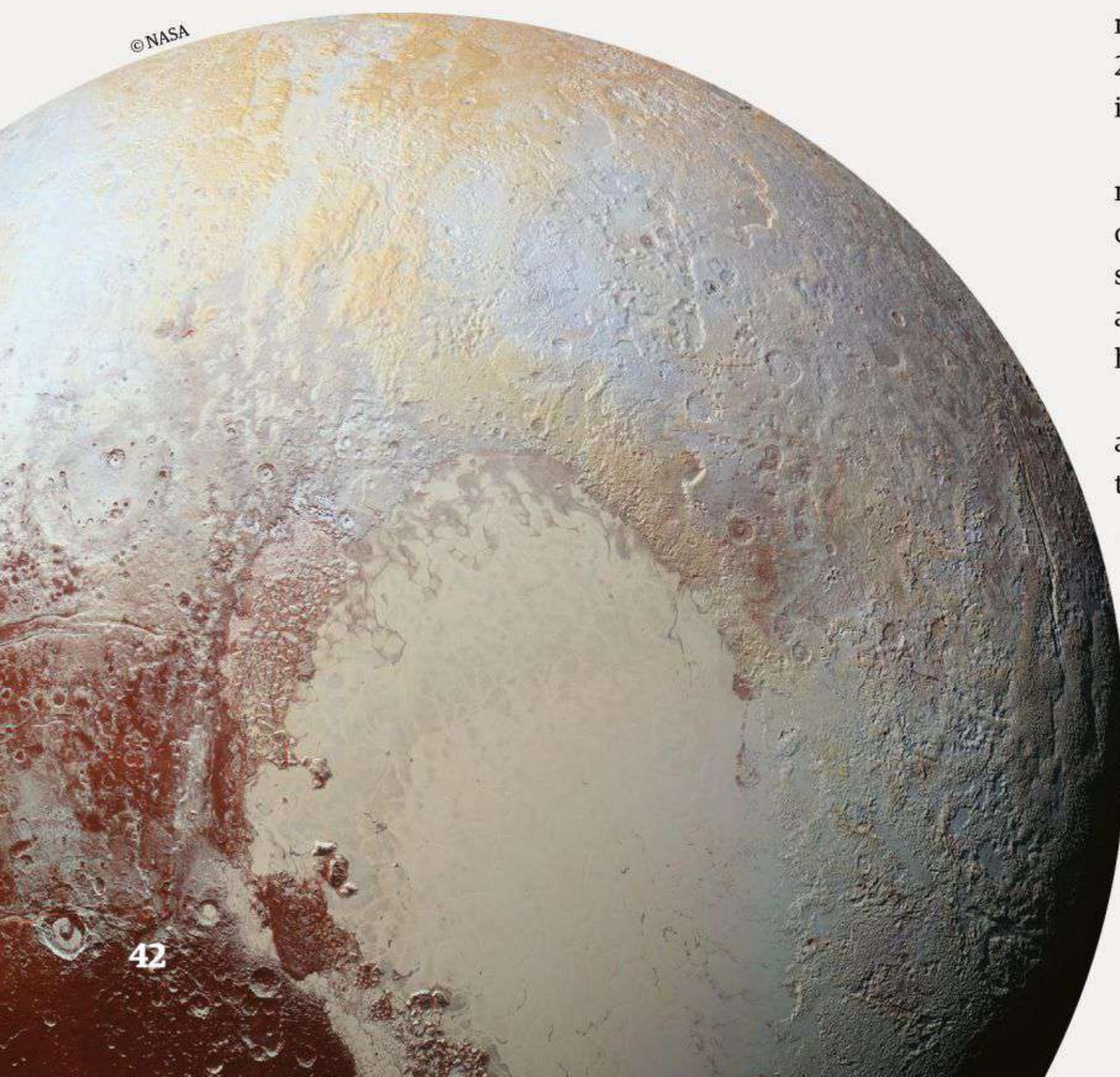
I am delighted that people think that *Cosmos* is just an annual thing. I'm delighted. But the effort and energy to do it, and to do it right and to come up with all the stories. Ann has unlimited creativity within her, so if she has it in her, it will happen. And I'm available to her if she needs or wants me for it, but it could be a time to bring other people in as hosts. [With] science, as I said, you pass a torch. Get someone younger. Get someone in who can bring in the next generation.

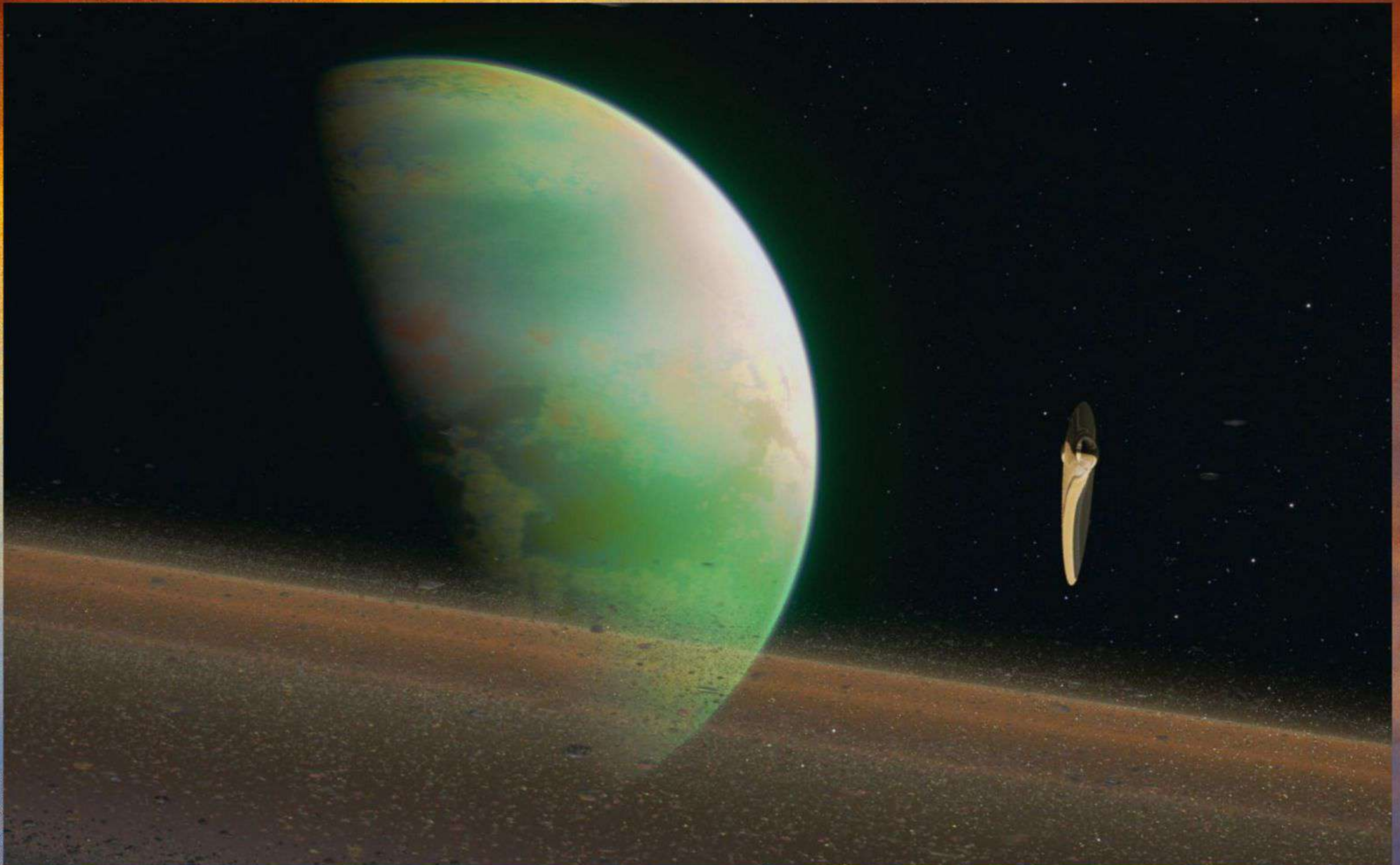
I think *Cosmos* is really a gift to all of us, to civilisation, to help us as such as entertainment. It's a mission statement so that we can become better shepherds of the civilisation that we have created.

Right: As a leading science communicator, Carl Sagan opened up the universe to a wider range of people

Below: Pluto was demoted from a planet to a dwarf planet in 2006

© NASA





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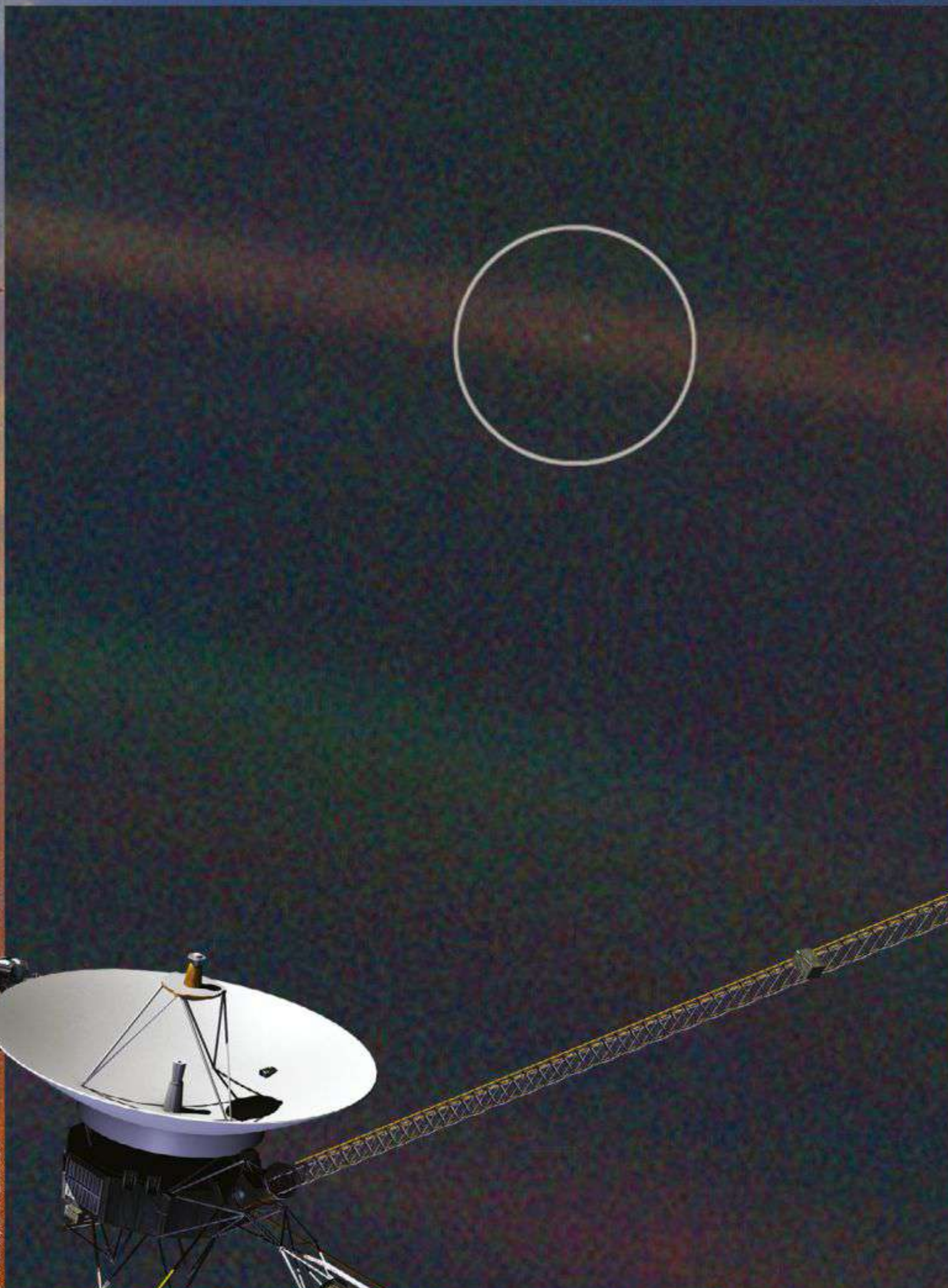
Top: This new series combines brilliant storytelling with immersive visual effects

Left: The 'Pale Blue Dot' was taken by the Voyager 1 spacecraft over 6.4 billion kilometres (4 billion miles) away from Earth

Right: *Cosmos: Possible Worlds* covers a range of exciting topics, from ancient history to the future state of the Sun



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WHEN DOES *COSMOS* RETURN?

Cosmos: Possible Worlds premieres 29 March 2020 at 17:00 GMT on National Geographic

GUIDE TO THE IMMORTAL PARTICLE

Could this be the answer to finding dark matter?
Particle physicists are on the hunt for a new
particle, the elusive 'sexaquark'

Reported by Lee Cavendish

HOW IT'S RELATED TO THE STANDARD MODEL

Particle physicists are always on the lookout for new elementary particles as they force a swarm of protons and electrons to collide within particle accelerators. The most famous of these is the Large Hadron Collider near Geneva, Switzerland, finding the Higgs boson in 2012. But now physicists are theorising new particles that could be out there.

The Standard Model of particle physics requires people to understand something even smaller than a particle. To put it as simply as possible, it is a list of the fundamental particles and forces which make up everything in the cosmos. This model was devised in the 1970s and has enabled physicists to prove the existence of several particles - it's hoped it will reveal the whereabouts of the sexaquark.

Of these building blocks, there are two groups of elementary particles that make up matter, and they are quarks and leptons. The group to focus on in the search for the sexaquark is quarks. There are six flavours of quark, and they differ in multiple properties, including charge but all have the same spin - which determines whether the particle rotates clockwise or anticlockwise. The six types are

called up, down, top, bottom, charm and strange, and they are held together by one of the four fundamental forces, called the 'strong' force.

Take atomic nuclei as an example. Atoms make up everything in the world, from a cell in your body to the tallest mountain. If you were to zoom in on an atomic nucleus, you would see it is made up of protons and neutrons. Zoom in once again and you'll see a proton is made up of two up quarks and one down quark, and a neutron is made up of two down quarks and one up quark.

Now particle physicists have hypothesised the existence of the sexaquark which, as the name suggests, consists of six quarks: two ups, two downs and two stranges. These six quarks, when held together by the strong nuclear force, would provide the particle with universally unique characteristics.

Right: An artist's impression of fundamental particles

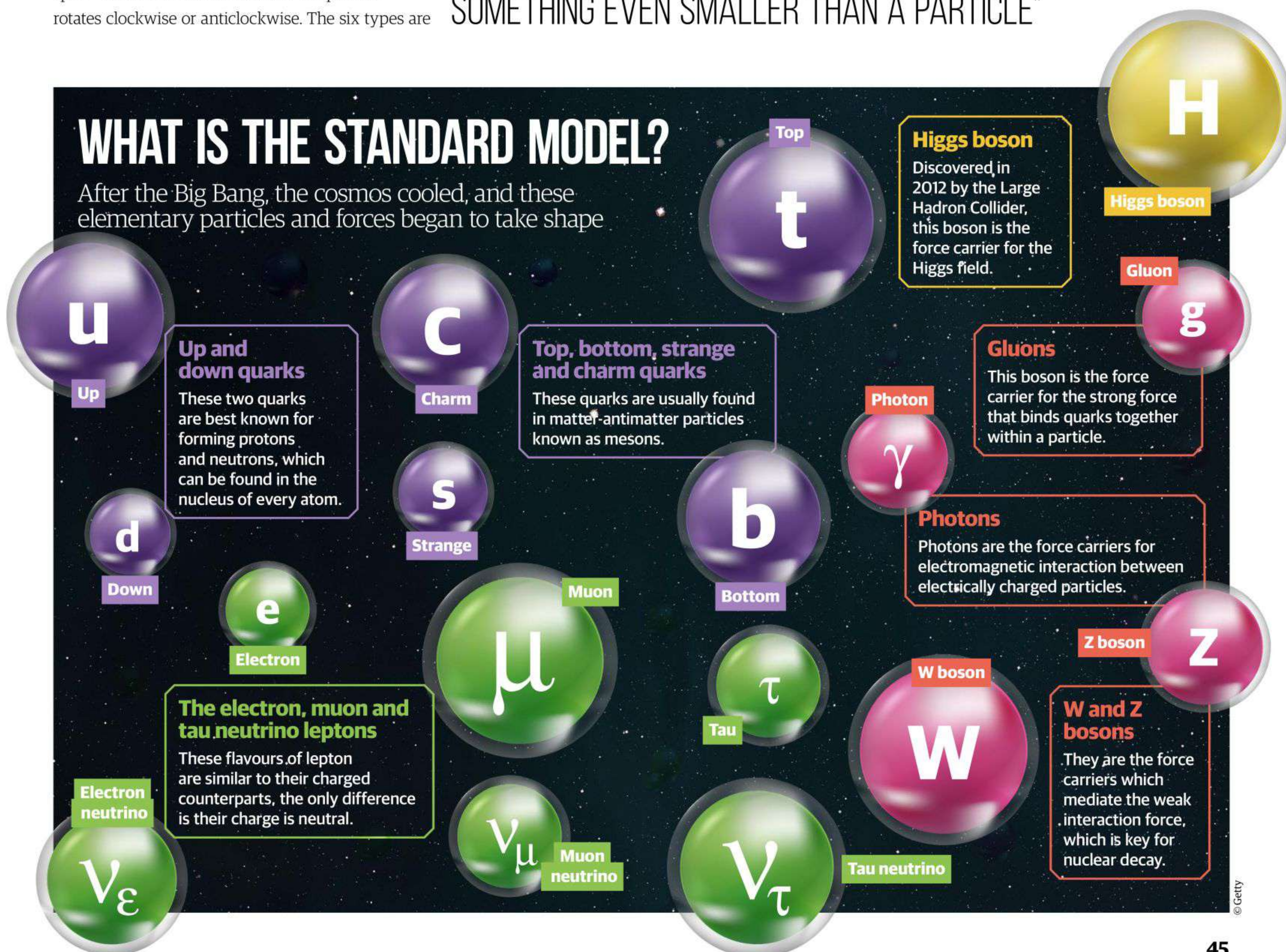


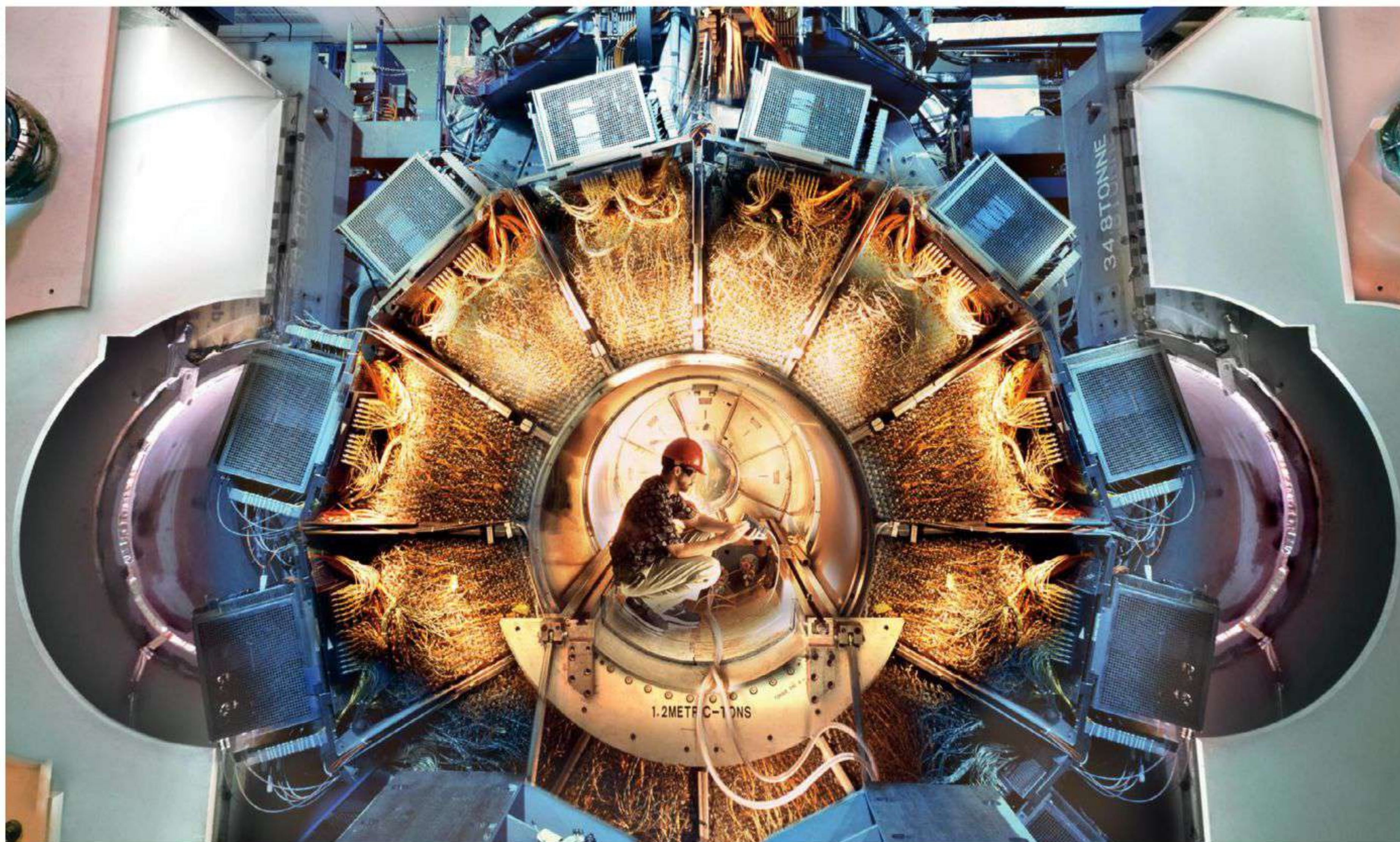
© Tobias Roetsch

"THE STANDARD MODEL REQUIRES PEOPLE TO UNDERSTAND SOMETHING EVEN SMALLER THAN A PARTICLE"

WHAT IS THE STANDARD MODEL?

After the Big Bang, the cosmos cooled, and these elementary particles and forces began to take shape





Left: The BaBar detector is located in California

Below: This simulation shows the Higgs boson decaying into four muons

WHAT MAKES THE SEXAQUARK IMMORTAL?

Particles and decaying tend to go hand-in-hand, giving rise to nuclear fission. Decay seems inevitable, and the rate varies between atoms depending on if they are heavy or light. If an atom is made up of more quarks, it is heavier, and therefore more unstable and susceptible to decay.

It's this decaying process that particle physicists look out for when searching for new particles, as it reveals the particle's properties. Without decay a particle could exist in an unaltered, stable state throughout the whole of time - in a word, immortal.

There are particles that are not quite immortal, but stay in a stable state for an incredibly long time. These are electrons, three types of neutrinos and photons - the lightest known particles, which

"DECAY SEEMS INEVITABLE, AND THE RATE VARIES BETWEEN ATOMS DEPENDING ON IF THEY ARE HEAVY OR LIGHT"

can drift through space for tens, hundreds or even thousands of billions of years.

Experimental physicists probing the properties of this new hypothetical particle have suggested that if the sexaquark is below a certain mass threshold, it can never decay. Even if its mass is a little bit higher than this threshold, it still has a lifetime that is comparable to the age of the universe - that's over 13.8 billion years old! If physicists know which combination they are looking out for, why haven't they picked up on the pesky particle yet?

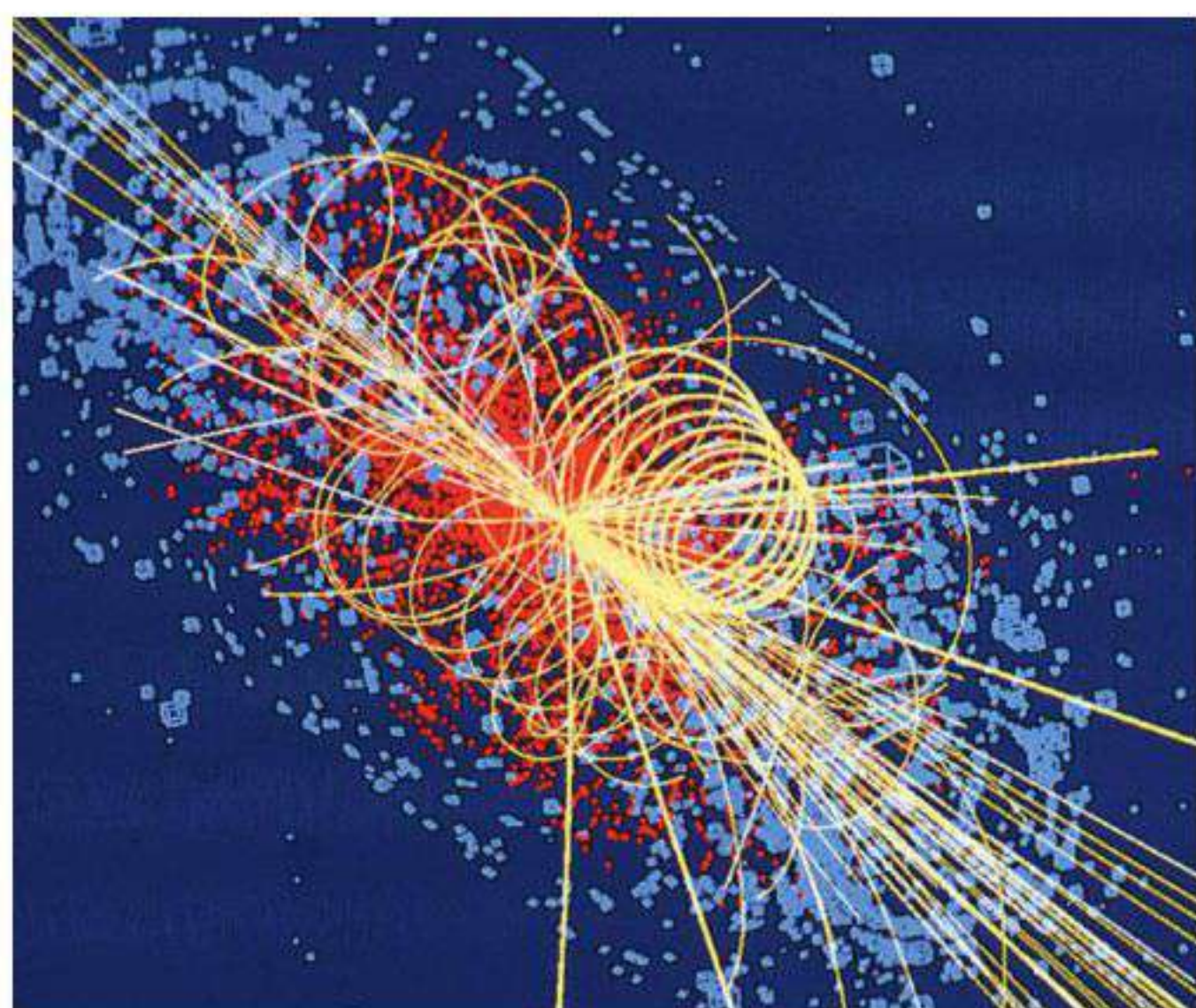
FINDING IT IS LIKE LOOKING FOR A NEEDLE IN A HAYSTACK

Particle accelerators are essential in revealing the fundamental particles that exist throughout the universe, and they do that by smashing all sorts of particles into each other. It's in time frames of less than a second that physicists can peer into the quantum world to see what new elementary particle - if any - has become uncloaked. Professor Romulus Godang at the University of South Alabama has recently used a particle accelerator in California to try exactly that.

The BaBar detector is part of an experiment at the SLAC National Accelerator Laboratory in California that specialises in combining quarks, with numerous combinations. This detector can even slam enough quarks together to form heavier, unstable particles that then decay into smaller and stabler ones with more rational arrangements.

This detector has a proven track record of success, helping Makoto Kobayashi and Toshihide Maskawa to win the Nobel Prize in Physics in 2008 "for the discovery of the origin of the broken symmetry which predicts the existence of at least three families of quarks in nature".

The results from Godang's experiments didn't show any signs of the elusive sexaquark, but in his conclusion he stated that this came with a 90 per cent confidence level. This leaves a ten per cent margin for the sexaquark to come to fruition, but it relies upon scientists catching a decay - from a heavier unstable combination of quarks into a sexaquark - that happens once in every 10 million decays. The lucky physicists saddled with this task need to be able to observe this incredibly rare event in a split second. But if they do catch a glimpse of the sexaquark, it could have revolutionary implications for our understanding of the equally elusive dark matter.



THE BABAR DETECTOR

A much more modest detector than the Large Hadron Collider, its capability to investigate the universe's most elementary particles should not be underestimated

1 Silicon Vertex Tracker (SVT)

Physicists rely on the SVT to track the locations of charged particles while also measuring their momentum and angles.

2 Instrumented Flux Return (IFR)

The IFR was designed to identify muons and to detect neutral hadrons, both to an extreme degree of precision.

3 Electromagnetic Calorimeter (EMC)

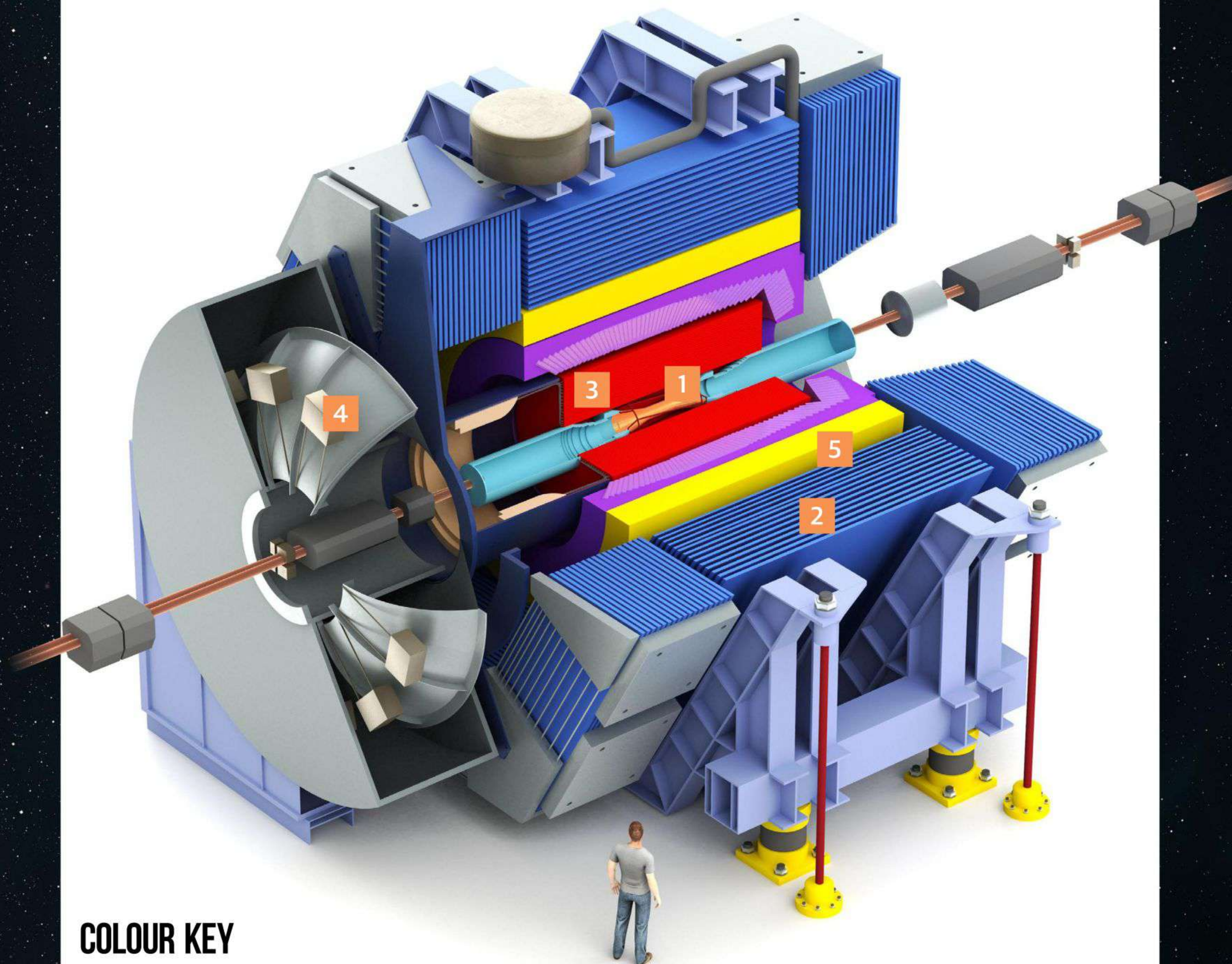
The EMC can identify and measure electrons passing through and can consequently help understand the flavour of mesons present within the detector.

4 Cherenkov detector (DIRC)

This detector is able to differentiate between charged particles of different masses.

5 Magnet coil

The superconducting solenoid enables the measurements of charged particles streaming through the detector's heart.



COLOUR KEY

■ Superconducting magnet coil
■ Muon/hadron detector

■ Drift/tracking chamber
■ Support tube

■ Electron/photon detector
■ Vertex detector

IT COULD BE THE ANSWER TO DARK MATTER

Particle accelerators only offer us a brief artificial window into what it was like at the dawn of the universe, when the entire cosmos was just a pressurised, scorching pool of quarks colliding. As this pool expanded due to the rapid inflation that followed, the quarks and leptons could then merge to form hydrogen and helium.

During this epoch of particle formation, it is theoretically possible that sexaquarks of the right mass range were formed in an enormous quantity and were able to survive the universe's initial infernal conditions. These sexaquarks could still be drifting around space in huge quantities today, never decaying and only interacting with other matter through the medium of gravity. This might sound a little familiar...

A collection of particle physicists believe that sexaquarks could be the most suitable candidate

for explaining dark matter. This mysterious matter makes up roughly a quarter of the entire universe. A mere five per cent of the universe is ordinary matter – this is matter we can see, whether it is planets, stars or galaxies – and the remaining 70 per cent is dark energy.

Dark matter is yet to have been observed directly, but astronomers are absolutely certain of its existence as it can be observed indirectly. In fact, in recent years astronomers have been able to map the distribution of dark matter in distant galaxies using a century-old mathematical calculation proposed by Albert Einstein. He stated that light can bend as it passes close to extremely large cosmic objects, such as galaxies; this means light from galaxies billions of light years away can be bent and focused towards Earth-based telescopes. This phenomenon is known as 'gravitational lensing', and this allows



© NASA/ESA

scientists to understand how much dark matter is in the 'lensing' galaxy.

The work conducted by Godang using the BaBar detector has not revealed the six-quark target as of yet, but with the particle's relatively light mass, it could be that it has just slipped under the radar. This research does not completely rule out sexaquarks as the answer for dark matter, but it does make it a harder challenge and will require much more intense scrutiny.

Above:
This image shows the distribution of dark matter in the galaxy cluster Abell 520

**SOLAR
SYSTEM HALO**

The dark matter halo is at least 300,000 light years across

85%

How much of the total mass in the universe is made of dark matter

1933

When Swiss astronomer Fritz Zwicky first proposed the existence of dark matter

**DARK
MATTER
IS *NOT*
ANTIMATTER**

**STATS AND FACTS
DARK MATTER**

Dark matter is one of the most misunderstood and fascinating subjects in astronomy. Here is some information that you may not know about this elusive substance

VERA RUBIN

In 1968 she showed compelling evidence that there is 'missing matter' in galaxies. Her work was based on observing the velocities of stars in the Andromeda Galaxy

**THE EARLY
UNIVERSE COULD
HAVE HAD DARK
MATTER STARS**

EUCLID

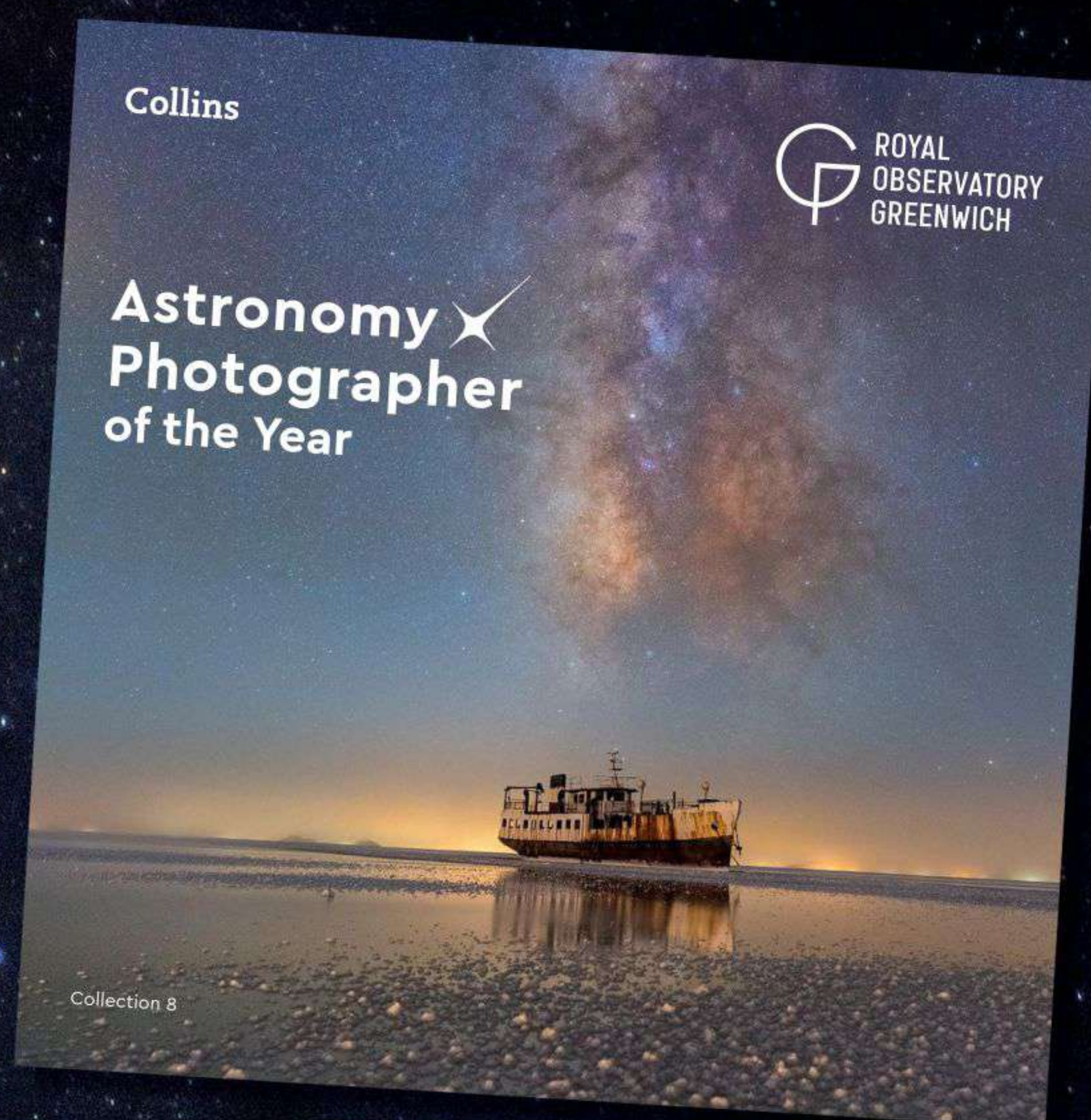
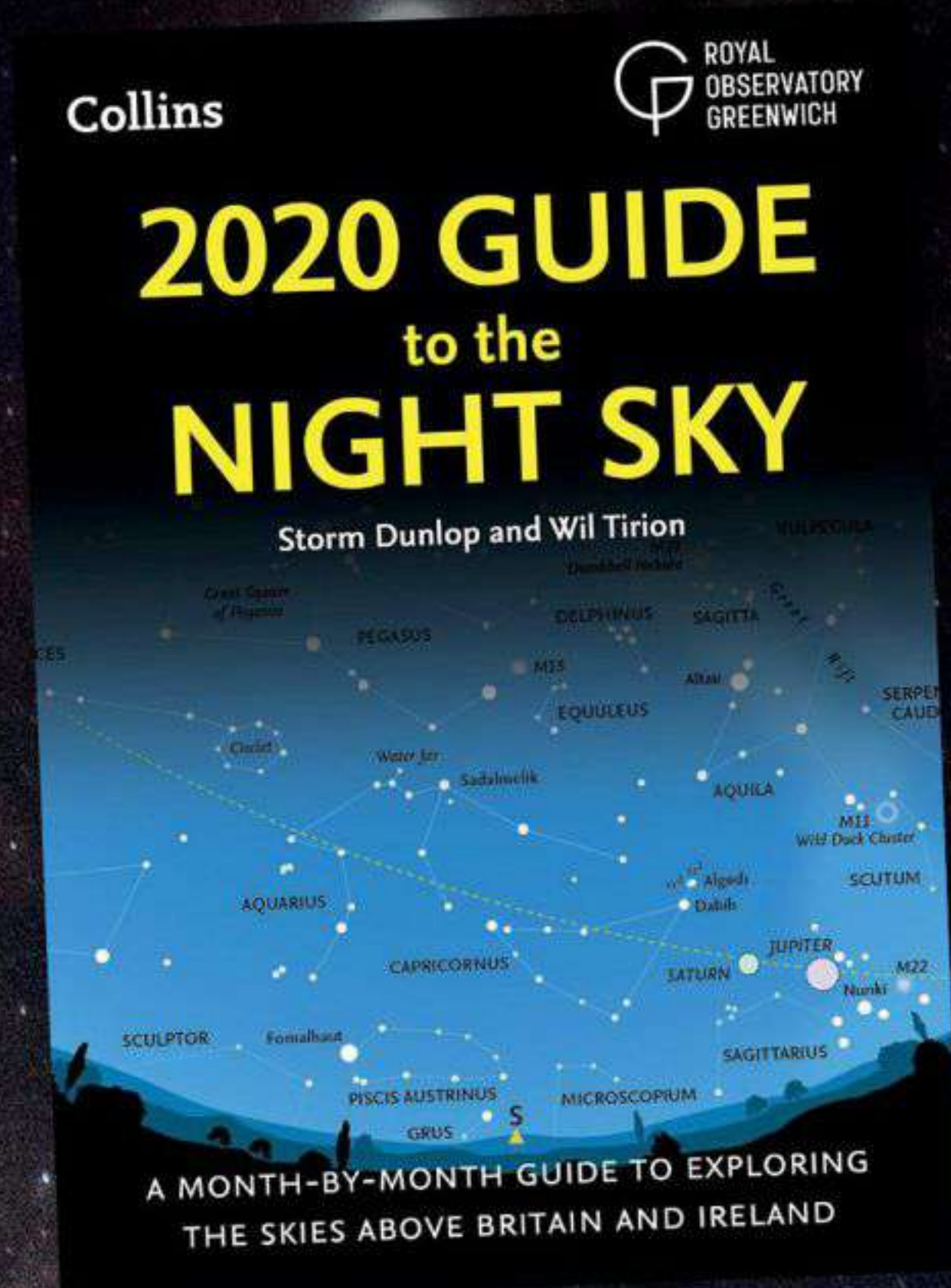
An ESA mission, due to launch in 2022, dedicated to studying dark matter

5

The number of *Star Trek* episodes that mention dark matter

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PLANET FORMATION: IS IT TURBULENT OR TRANQUIL?

There are so many different types of planets - terrestrial planets like Earth, gas giants like Jupiter and dwarf planets like Pluto - but every cake must start with simpler ingredients, and planets are no exception. For planets these are the gases and minute dust particles that circled the infant Sun in the vast flattened disc we call the 'protosolar nebula'. Laboratory studies of meteorites and astronomical studies of protostellar discs around nearly baby stars have also told us that however it happened, planets must form quickly, astronomically speaking, within a few million years. This revolutionised our thinking about how planets form.

The small particles in the protosolar nebula can stick together and form pebble-sized particles, but the process can't continue indefinitely to larger and larger sizes because as pebbles grow they strike each other at greater and greater speeds and end up demolishing each other. But when there are enough pebbles in a cloud, that cloud will collapse in upon itself due to its own gravity, and just like that you get a planetary building block - a planetesimal. The best part is that we don't have to go back in time to see one; we just have to go to the Kuiper Belt, beyond the orbit of Neptune.

On 1 January 2019, NASA's New Horizons spacecraft flew by a Kuiper Belt object called Arrokoth. This body was chosen for the flyby because small worlds in this part of deep space have been left more or less undisturbed since the Solar System's inception 4.5 billion years ago. What New Horizons saw, however, was actually two bodies, each flattened like lentils and gently assembled into a contact binary. No evidence of a violent merger or collision is evident. This is precisely what is predicted in computer simulations of planetesimal formation in a collapsing pebble cloud, which is that binaries often form and gently merge.

Once you have planetesimals, it's game on. Planetesimals can collide, merge and accrete more pebbles as they grow to larger sizes. If they get really big - becoming protoplanets - they can attract gas directly from the nebula and become planets like Jupiter. Protoplanets themselves can also collide with spectacular results, with one example being the formation of Earth's Moon.

3. Pebbles to a rocky swarm

The gas around the pebble-sized particles will then herd the particles into great swarms and clouds, which will then collapse under their own gravity and initiate the collisions.

1. Starting from gas

From moons to supermassive black holes, every object in the universe was initially formed from a cloud of gas and dust.

BIO

PROF WILLIAM B. MCKINNON

McKinnon is professor of Earth and planetary sciences at Washington University in St Louis, Missouri. His primary research focuses on the icy bodies that reside in the outer Solar System in a region known as the Kuiper Belt. However, this is just a part of his much wider understanding of the formation and evolution of the entire Solar System.



4. Clouds of pebbles to planetesimals

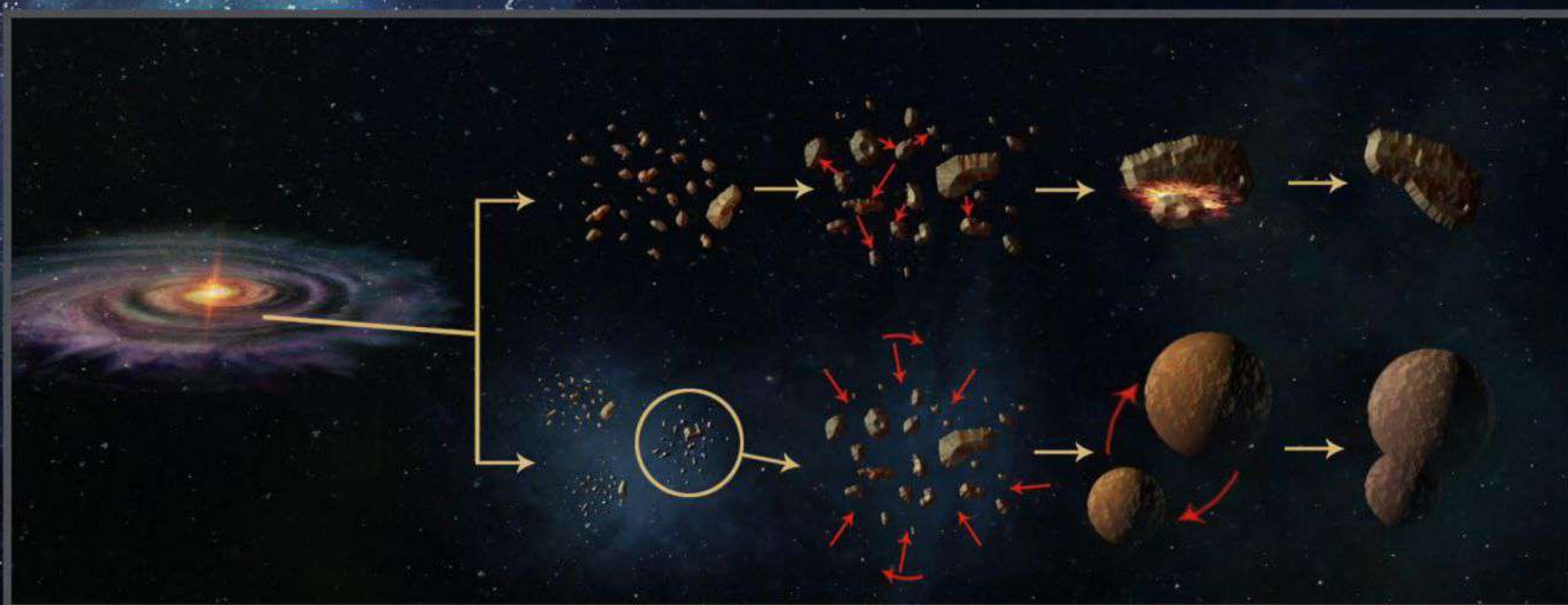
The formation of planetesimals is much less violent than the public perception, with the observations of Kuiper Belt object Arrokoth revealing that objects merge gently.

5. Planetesimals to planets

The planetesimals then attract the attention of more leftover debris, which then creates the final form of a planet and the base for life.

2. Gas to pebbles

After the host star is formed, the leftover gas provides the fundamental ingredients for planetary formation, beginning with the accretion of pebble-sized particles.





Signed into law in 2019, what will this new branch of the US military actually do?

Reported by Jonathan O'Callaghan

The idea of a space force sounds a bit bizarre. Why do we need a branch of the military protecting us from space? While the reasoning behind it might not be to everyone's liking, there is actually a purpose for a space force. And while it won't be protecting us from evil invading aliens heading to our planet, it is designed to potentially address conflicts in space - a type of warfare that might indeed be alien to many.

The United States Space Force (USSF) is a branch of the US Armed Forces first announced by President Trump in mid-2018. Trump said the force was intended to protect "American dominance in space". His former secretary of defense, James Mattis, referred to space as a "warfighting domain" and said the US needed to be wary of other countries acting in space. They decided the best way to deal with this was by a show of strength. Trump formally established the Space Force as a new branch of the US military in December 2019. It has its own logo and its own head, General John Raymond, who is the agency's chief of space operations. At the time of writing, plans are afoot to change the names of key bases in the US over to the Space Force. Cape Canaveral Air Force Station looks set to become the Cape Canaveral Space Force Station, while the Vandenberg Air Force Base could become the Vandenberg Space Force Base.

By and large, the Space Force appears to be an attempt to turn what was a very offhand comment by Trump two years ago into actual policy. "Congress took a seemingly flippant remark and created a rational implementation plan, a Space Force to support Space Command,"

Joan Johnson-Freese, a professor of national security affairs at the Naval War College in Newport, Rhode Island, said earlier this year. "Whether it will evolve into an organisation that solves any of the problems that prompted it remains to be seen. On the negative side, it certainly increases the perception that the US is leading the way in the weaponisation of space."

American military operations in space are broad. They include operating satellites, performing tests and keeping an eye on the activities of several rival countries in space, notably China and Russia. In February 2020 it was revealed by General Raymond that a Russian satellite had been tailing a US spy satellite in space, for example. Approaching to just 160 kilometres (100 miles) from the US satellite, it was believed Russia was spying on the US satellite and taking a look at how it worked. "We view this behaviour as unusual and disturbing. It has the potential to create a dangerous situation in space," Raymond said at the time.

Below: Trump signed the National Defense Authorization Act in late 2019 to make the Space Force a reality



Source: Wikipedia Commons



© United States Space Force

Prior to the creation of the Space Force, US activities in space were handled by the US Air Force, more specifically Air Force Space Command. This included the management of launch complexes in the US and more intricate details like the tracking of satellites in space. Now that the Space Force has been created, it's believed that many of these activities will shift over to the new branch of the US military. But many aspects, such as space military research and funding, remain unclear as to how they will progress - the US Department of Defense (DOD), for example, has been very slow to relinquish control of the Space Development Agency. The plan is to shift it over to the Space Force by late 2022.

About 60 different parts of the US military are currently involved in space, while Air Force Space Command boasts about 36,000 people. The idea is that the Space Force could take over many of these operations, providing one single hub to tackle all areas and bring people from different branches together. Some have questioned why a Space Force is needed at all when these parts of the US military already function with few issues, but others have

noted a greater need to unify everything under one roof. And the US is not alone in having a space force - Russia, for example, has boasted its own Russian Space Forces since the 1990s.

There is still the question, however, of what the Space Force will do exactly. It will not be fighting aliens in space, despite having its own uniform. It will, however, try and tackle some of the growing concerns about space activity in order to protect many of the US assets currently in space. There are concerns that some countries or rogue organisations might possess anti-satellite technology, for example, able to shoot down satellites using missiles or even powerful lasers. The Space Force will be tasked with making sure that doesn't happen.

It's unlikely, however, that the Space Force will have much involvement with NASA. While the latter does occasionally cooperate with the Air Force on space matters, the two are mostly separate, with NASA focusing on scientific space activities. It's likely that the Space Force will continue in the same manner, with some minimal cooperation with NASA, perhaps on launches and other matters, but

SPACE FORCE UNIFORMS

Mocked slightly at their unveiling, here is what the personnel are likely to wear

The same for all

Space Force uniforms are standardised for everyone in the force so that they are easily recognisable from other branches of the military.

Camouflage in... space?

The use of camouflage on the uniform might be surprising, but this is just keeping it in line with the design of the Army and Air Force.

Space Command

A badge is visible on the sleeve denoting this part of the military that was formed around the same time as the Space Force.

American flag

The stars and stripes of the US flag are visible on the uniform, which is the same across all US military uniforms.

Branch identifier

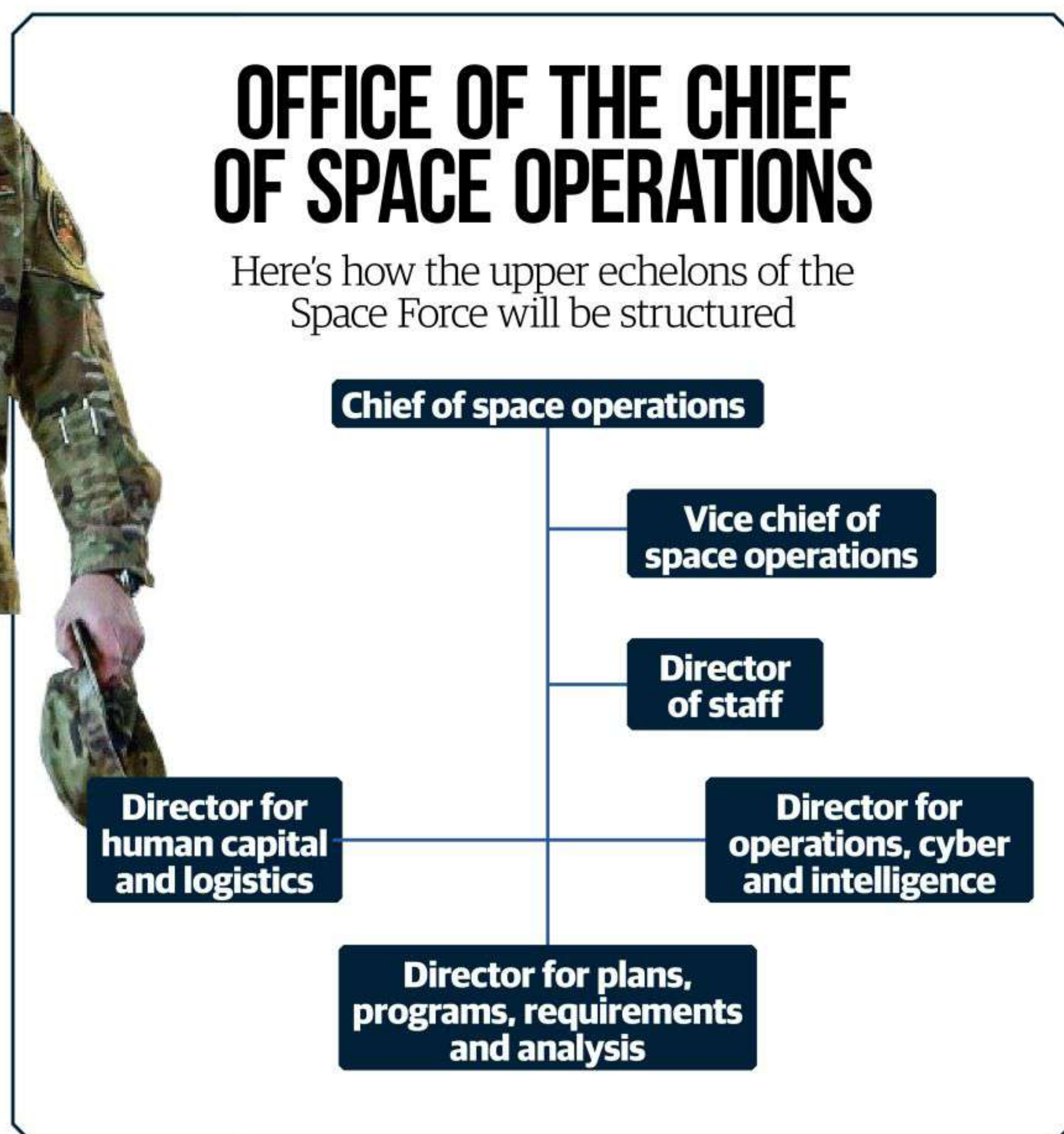
The text 'US Space Force' is clearly visible on the uniform, just in case anyone might get confused with members of the other military branches.



"IT CERTAINLY INCREASES THE PERCEPTION THAT THE US IS LEADING THE WAY IN THE WEAPONISATION OF SPACE" JOAN JOHNSON-FREESE

OFFICE OF THE CHIEF OF SPACE OPERATIONS

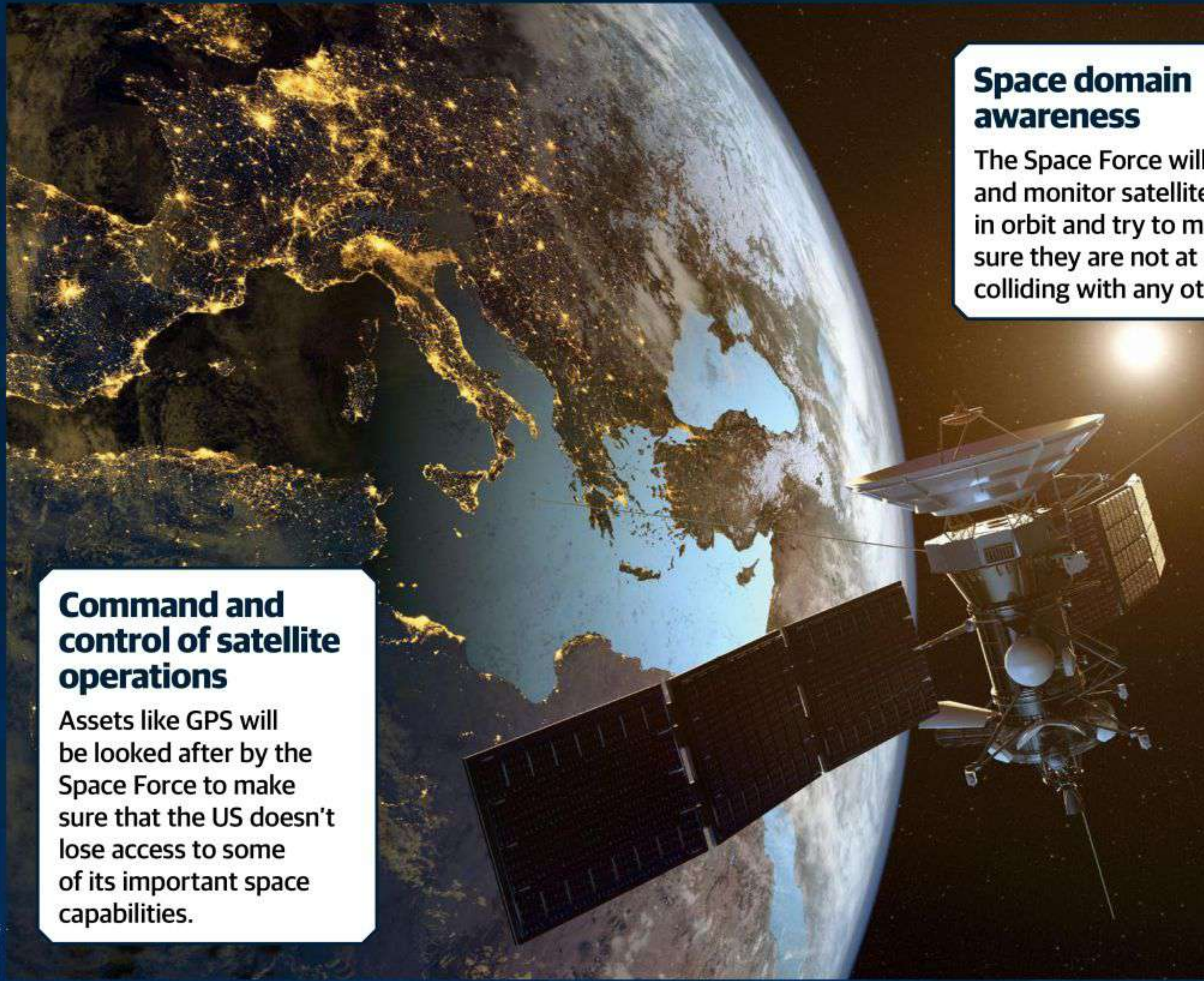
Here's how the upper echelons of the Space Force will be structured



© United States Space Force

WHAT ARE THE AIMS OF THE SPACE FORCE?

What does the department actually plan to do, and how does it plan to do it?



Command and control of satellite operations

Assets like GPS will be looked after by the Space Force to make sure that the US doesn't lose access to some of its important space capabilities.

© Getty

Space domain awareness

The Space Force will track and monitor satellites in orbit and try to make sure they are not at risk of colliding with any others.



© NASA



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Missile warning

The Space Force will continue developing satellites to monitor any missile launches that might threaten the US, its forces deployed around the world or any of its allies.



Space support to operations

This includes making sure that military services on the ground that rely on space-based capabilities, like satellites, are not interrupted and continue operating.

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© SpaceX

Space superiority

The Space Force is designed to make sure the US remains a leader in all space activities. This means having continuing access to space, including the launch and operation of satellites.

WHO'S INVOLVED?

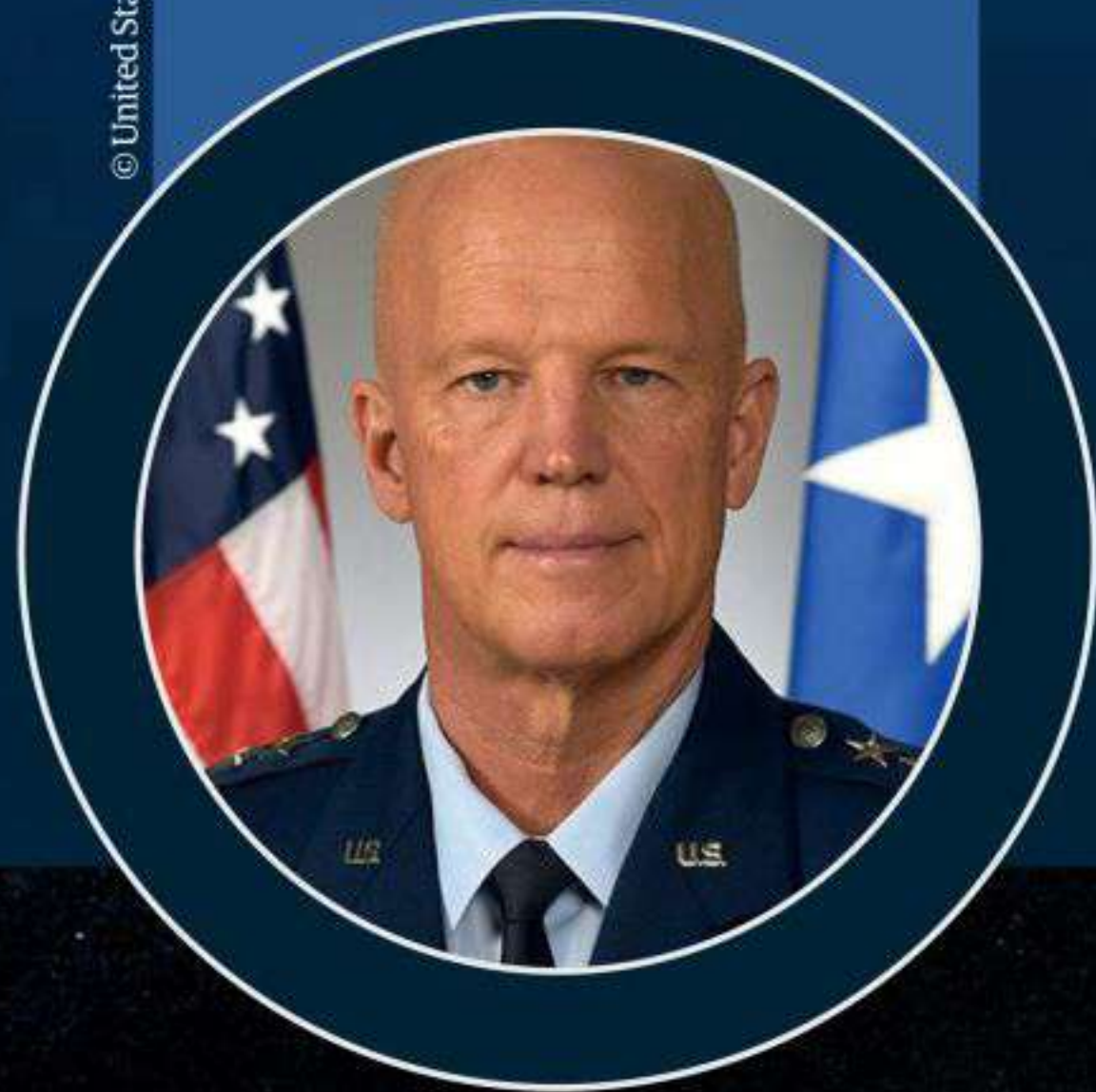
At the moment the Space Force has only one member, but thousands more are expected to follow

General John Raymond

Role in Space Force:
chief of space operations

General Raymond is in charge of leading the US Space Force, being its first chief of space operations. He was announced in the role by President Trump in 2019, and is now in charge of getting the fledgling branch up and running.

© United States Space Force



Below: There is a lot of space debris orbiting Earth that needs to be tracked

for the most part the two will be kept separate from each other.

As mentioned earlier, the Space Force will likely also be responsible for managing many of the launch operations in the US, more of a bureaucratic switch than anything. It may also take over the running of key space research programs in the future. The Air Force, for example, has been busy developing a mysterious space plane called the X-37 for the last two decades. In the future projects like this may be more directly handled by the Space Force, which some might argue would make sense anyway. Why is the Air Force conducting tests in Earth orbit in the first place?

The Space Force is expected to have a budget of \$2 billion over the next five years, with roughly 15,000 personnel expected to transfer over to it from other branches of the US military. However, it's not yet clear how or when people will be able to apply to enlist in the Space Force, or whether that will even be possible. Will it have recruitment centres like the Air Force? That's another major

unknown about how it will operate. It's also not clear if soldiers will be trained within the Space Force, like other branches of the military.

However, we do have a vague idea of what it will do, namely taking all the other space activities from other branches of the US military and bringing them together. It will be headquartered at the Pentagon and initially will be part of the Air Force before becoming its own true branch at the end of 2020. According to a 'fact sheet' released by the US government in 2020, the Space Force "is a military service that organizes, trains and equips space forces in order to protect US and allied interests in space and to provide space capabilities to the joint force. USSF responsibilities include developing military space professionals, acquiring military space systems, maturing the military doctrine for space power and organizing space forces to present to our Combatant Commands."

According to the fact sheet the Space Force will also "maintain and enhance the competitive edge of the DOD in space while adapting to new strategic

"IT'S LIKELY THAT THE SPACE FORCE WILL CONTINUE IN THE SAME MANNER, WITH SOME MINIMAL COOPERATION WITH NASA, PERHAPS ON LAUNCHES AND OTHER MATTERS"



challenges". One example of this is the Global Positioning System (GPS), a small constellation of satellites that provides positional data not only to users on the ground, but to the military as well. Were GPS to be targeted, it could have major impacts on how the US conducted its own ground operations, and potentially halt them entirely.

The Space Force will also take over the monitoring of positional data for satellites in orbit, currently handled by US Strategic Command. This allows satellites orbiting Earth to avoid collisions with each other - by keeping track of where satellites are, the US military can alert any satellite operators if they are on a potential collision course with another satellite. This capability is vital to making sure Earth orbit remains usable by countries and companies, preventing collisions that cause large amounts of debris. And according to the Space Force's published goals, this is one of the areas it will be responsible for.

Similarly, the US operates a number of reconnaissance satellites in orbit, along with other military hardware. The Space Force will most likely be tasked with operating these satellites, or at least ensuring they remain in service. These satellites allow the US to peer into other countries, returning images of extremely high resolution of distant targets. They are a vital part of the US military's activities around the world, and if someone were to try and take them out, there could be severe consequences for how the military operates. It makes sense they'd like to keep them relatively safe.

The Space Force will not, however, put people into space. Contrary to its name, it will not involve any sort of human fighting force being sent into orbit or beyond. While there has been discussion that the Space Force could be involved in some futuristic aspects of space exploration, such as asteroid mining, there are no current plans to actually send anyone to space. Don't expect to see any Space Force personnel suddenly popping up on the International Space Station!

The main purpose of the Space Force is to bring all the spacey goodness of the US military together. However, there have been some concerns that its very creation is somewhat an act of aggression against others in space. By proclaiming space as a "warfighting domain", the US has quite clearly drawn battle lines - a little ironically, however, if there was actually a war in space, this would be handled by US Space Command, not the Space Force. With Russian satellites already performing questionable operations in orbit, and China rapidly expanding its space activities, the potential for some sort of conflict to erupt in space, and possibly feed down to Earth, is ever-present.

"Space is the world's newest warfighting domain," Trump said at the signing ceremony for the Space Force in December 2019. "Amid grave threats to our national security, American superiority in space



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DO WE REALLY NEED A SPACE FORCE?

is absolutely vital. And we're leading, but we're not leading by enough. But very shortly, we'll be leading by a lot. The Space Force will help us deter aggression and control the ultimate high ground."

And in a statement, General Mark Milley, chairman of the joint chiefs of staff, laid out some of the reasoning behind the Space Force. "Our adversaries are building and deploying capabilities to threaten us, so we can no longer take space for granted," he said. "The US Space Force is the necessary and essential step our nation will take to defend our national interests in space today and into the future."

Whether that is really true is up for debate, but like it or loathe it, the Space Force is already here, and it's not going anywhere anytime soon. It might not quite be the dawn of laser battles in space, but it does herald the beginning of a new era where countries become increasingly nervous about their sensitive assets in space. And if everyone can't get along nicely, maybe something like the Space Force will be necessary. For the time being it is simply a bureaucratic reshuffling of US space activities - and many hope it will remain that way for the foreseeable future.

Top: The Space Force will track and monitor satellites orbiting Earth to prevent collisions

Above: Many US military operations rely on space capabilities to be successful

For: Space is absolutely vital to the US, and to its military capabilities. It relies heavily on satellites to provide images and communications for its military on the ground, and if another country or rogue actor were to threaten this capability, it would be disastrous. Having a branch of the military to protect all space activities seems to make sense.

Against: Many feel that space should be used for peaceful purposes, not for militaristic ones. While the military does make use of space, any escalation of tensions in Earth orbit could be disastrous. Creating the Space Force may only make the chance of conflict in space, rather than peaceful resolution to any disagreements, more likely.



PHOTO GALLERY
**POSTCARDS
FROM THE
SUN**

NASA's Parker Solar Probe (PSP) has
made it closer to our nearest star than
any human-made object

Reported by Lee Cavendish



OVER A MILLION PASSENGERS

NASA is always looking for public participation and interest in its missions as it seeks to inspire a new generation of astronomers and engineers. Prior to the launch of the PSP, NASA launched a different mission to get as many names on the spacecraft as possible. Through the NASA website, anyone was able to sign up with their name and email address to put their name on the first-ever mission to 'touch' the Sun. This led to the addition of a microchip on the spacecraft that holds an outstanding 1.1 million names!

Along with its 1.1 million passengers there are photos of Eugene Parker and a copy of his 1958 scientific paper titled 'Dynamics of the Interplanetary Gas and Magnetic Fields', which first suggested the existence of solar wind and other concepts about stars. This microchip is encased within a plaque that has a beautifully simplistic quote from Parker himself: "Let's see what lies ahead."

"NASA launched a mission to get as many names on the spacecraft as possible"

THE MAKE OR BREAK MOMENT

At the tip of the United Launch Alliance's Delta IV Heavy rocket was the PSP spacecraft, which measures roughly the size of a car. The probe survived what many would consider a make or break moment, the launch, which took off from Space Launch Complex 37 at Cape Canaveral Air Force Station in Florida.

On 12 August 2018, NASA entrusted a multi-stage vehicle, which runs on fuel and fire, with transporting the centrepiece of a £1.2 billion (\$1.5 billion) project into space. There is always the chance that things could go wrong, and that's not even taking into account the violent vibrations caused by the launch.

Liftoff was a success, with the team excited for what the next seven years would reveal. "Today's launch was the culmination of six decades of scientific study and millions of hours of effort," said project manager Andy Driesman of the Johns Hopkins University Applied Physics Laboratory (APL) in Laurel, Maryland. "Now the Parker Solar Probe is operating normally and on its way to begin a seven-year mission of extreme science."



PARKER WATCHES PARKER BLAST OFF

Eugene Parker looks on as his namesake is cast into the cosmos on a revolutionary mission to the Sun. The astrophysicist holds the very prestigious honour of being the only living scientist to have a NASA mission named after them. The agency renamed the mission from 'Solar Probe Plus' to the 'Parker Solar Probe' in May 2017 in honour of his contributions to the field of solar physics.

Parker serves as the S. Chandrasekhar Distinguished Service Professor Emeritus at the University of Chicago, but back in the 1950s and 1960s he was a young professor who released a series of groundbreaking papers about the workings of stars, including our Sun. His 1958 scientific paper outlined that there are waves of matter and magnetism being thrown from stars into the surrounding space, where it then interacts with all objects and planets it encounters. This phenomenon was called the 'solar wind', and has since been observed through direct observation.



THE TEAM CELEBRATE SURVIVAL

This small gathering may not seem like much, but it was an important moment of celebration as the PSP survived its first close-up encounter with the Sun. Before this joyous moment, the PSP team were sat in Johns Hopkins University's Applied Physics Laboratory on 7 November 2018, waiting for a signal to arrive indicating that the solar probe had survived its first flyby and that all instruments were operating well and conducting their scientific duties.

During this flyby the spacecraft was travelling at speeds of up to 343,000 kilometres (213,200 miles) per hour through a harsh and threatening environment. This speed record will continue to be broken as the spacecraft conducts multiple gravity-assist flybys of Venus, slingshotting it closer and closer towards the Sun's surface each time.



THE MILKY WAY THROUGH FRESH EYES

After launch, engineers wanted to make sure that everything on the spacecraft was functioning, as vibrations during liftoff have the potential to cause damage. Once the solar probe began its journey to the Sun, each of the four instruments that make up the full investigative instrumental suite were fired up. This image was taken by the Wide-field Imager for Solar Probe (WISPR) instrument in an initial test shot. Although it provides no real scientific value, it did certify that the instrument worked and provided a stunning view of the Milky Way.

Along with the WISPR instrument, the other instruments that were tested include the FIELDS experiment, the Solar Wind Electrons Alphas and Protons (SWEAP) investigation and the Integrated Science Investigation of the Sun (IS^{IS}) equipment. Collectively these instruments will scrutinise the nearby solar environment, from the electrons and protons that are whizzing around to the electric and magnetic fields that invisibly influence the region.





LOOKING BACK AT EARTH

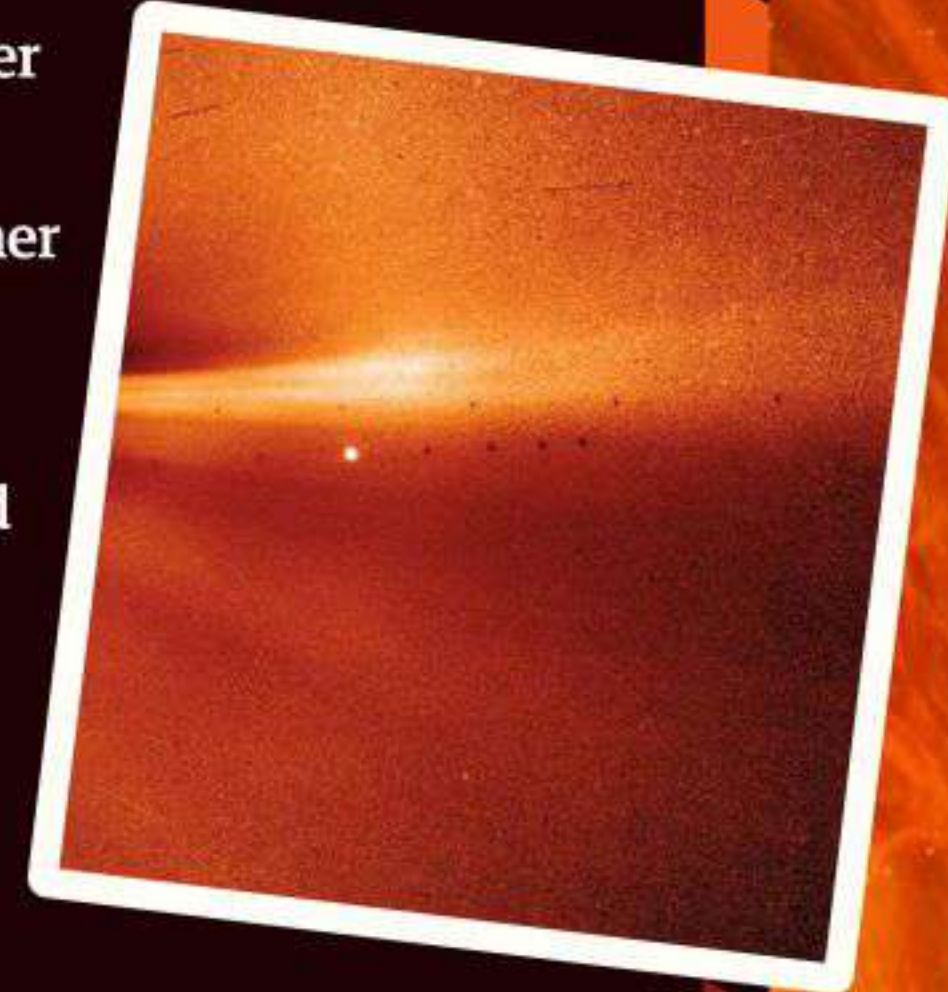
On 25 September 2018, over a month after launch, the solar probe looked back at its starting point, Earth. This picture was taken 43.5 million kilometres (27 million miles) away from the planet while the probe was on its way to Venus to begin the first of seven gravity-assist flybys. And before anyone tries to claim that the elongated mark in the right-hand frame is a UFO, let's clear that up... it's not. This mark is just the lens reflection of a bright object cast onto the WISPR instrument. Some of our more keen-eyed readers may be able to name the collection of bunched-up stars sitting to the lower left of Earth, which are the Pleiades, also known as Messier 45 or the Seven Sisters.

The WISPR instrument is unique in that it is made up of two telescopes pointing in different directions. They are protected in a way that means they cannot be overheated and damaged by the Sun's intense radiation during a solar flyby, while at the same time it allows an opening to image the Sun's corona and inner heliosphere. By imaging the solar atmosphere, astronomers can collect unprecedented data on the solar wind, shocks and other ejecta.

UNDERSTANDING THE CORONA

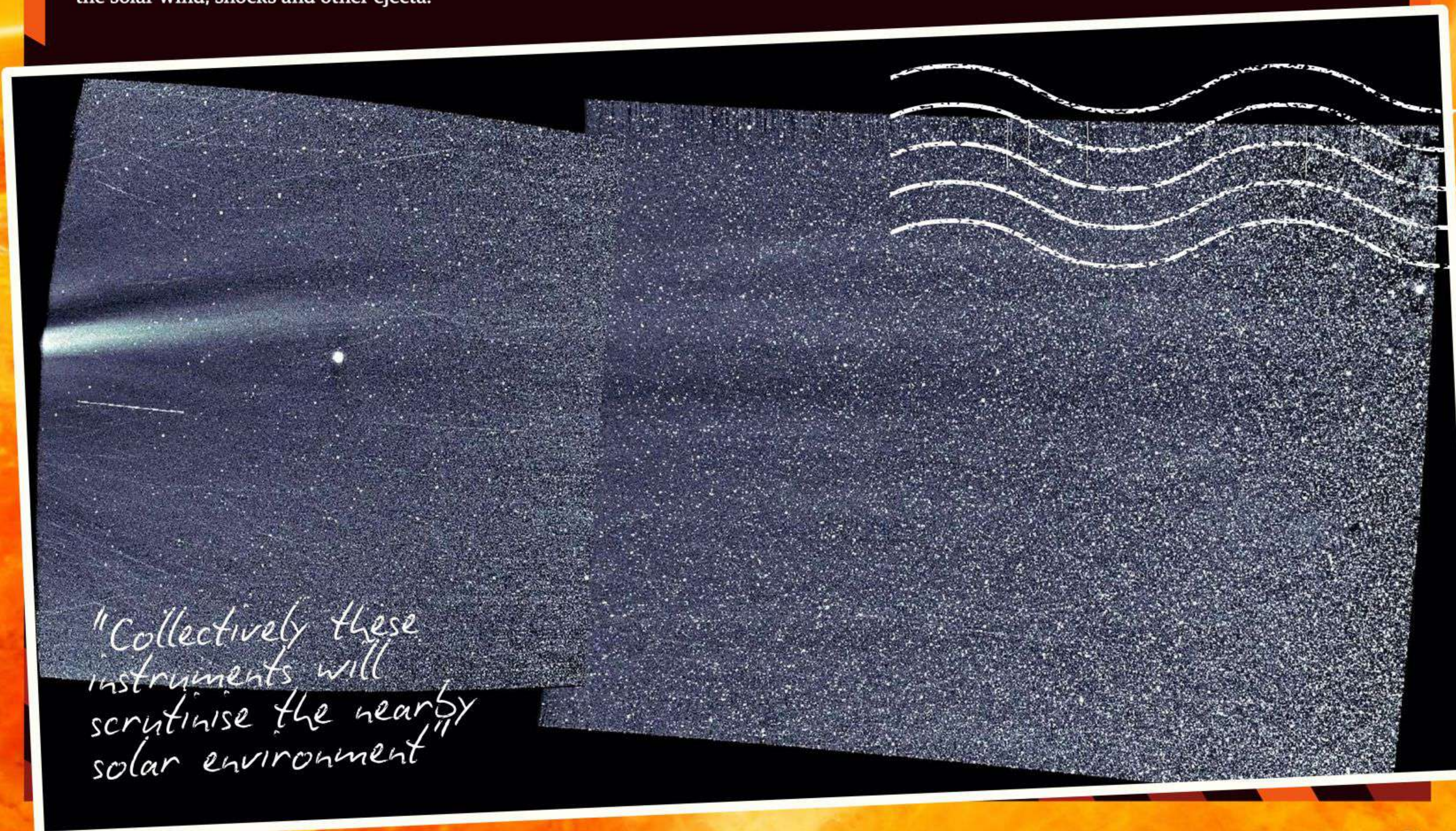
This image was taken during the November 2018 flyby, but this has been colour corrected to emphasise the coronal streamer emerging from the eastern limb of the Sun. The black dots aren't the result of a mysterious solar phenomenon, but instead the result of background correction.

The Sun's corona is arguably the Solar System's most misunderstood and influential region. It's the uppermost part of the Sun's atmosphere but is over a million degrees Celsius. When compared to the Sun's chromosphere, which is often referred to as the 'surface' of the Sun and has a temperature of 4,320 degrees Celsius (7,800 degrees Fahrenheit), it is clear there is a mechanism in place causing the corona's outrageously high temperature.



THE ANNIVERSARY SNAPSHOT

The below image was taken by the WISPR instrument and has the Sun out of the frame to the left-hand side. The solar wind is one of the main phenomena that the PSP intends to study extensively, and it can be seen sweeping through space from left to right in this image. The bright eruption that can be seen to the left is a dense and slow surge of particles referred to as a 'coronal streamer'. The thin, white streaks in the image are actually particles of dust passing in front of WISPR, while the bright celestial object in the background is a planetary 'photobomb', courtesy of Mercury.



"Collectively these instruments will scrutinise the nearby solar environment"

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MYSTERIES
OF THE
UNIVERSE

MYSTERIOUS BURSTS FROM SPACE

Not only have strange signals been discovered from deep in the universe, one is repeating itself every 16.35 days

Reported by David Crookes

Fast radio bursts, or FRBs, are bright flashes of radio emissions that only last a fraction of a second. But ever since they were discovered in 2007 by Duncan Lorimer and David Narkevic using data taken by the radio dish at the Parkes Observatory in Australia, astronomers have devoted many hours, days, months and years to figuring out what may be causing them.

In truth, it hasn't been an easy task. Over all that time, these transient radio pulses have only been detected a little over 100 times, and because they are typically observed to burst only once, it has been very tricky to pinpoint exactly where they have been coming from, making further study near-impossible.

"The difficulty in localising FRBs within distant galaxies stems from the fact that the vast majority of them are detected only once," affirms



RADIO BURSTS BY THE NUMBERS

110

Number of FRBs found so far

1

Number of FRBs found repeating in a steady cycle

16.35

Days involved in the cycle of FRB 180916.J0158+65

4

Days when the FRB is active in a cycle

500 MILLION

Light years away from Earth

28

Number of bursts recorded from FRB 180916.J0158+65

2

Maximum number of bursts per hour

5

Number of FRBs associated with a host galaxy

Below: When FRB 180916.J0158+65 was discovered by CHIME, it was pinpointed to a nearby spiral galaxy, marked here with a green circle

American theoretical physicist Avi Loeb, who is professor of science at Harvard University. What's needed are signals that repeat, and as luck would have it, a few handfuls have been found.

The first repeater FRB was observed in 2012, with the frequent hiccups of FRB 121102 turning expectations and theories on their head. Before it was discovered astronomers were of the mind that FRBs were being caused by a single cataclysmic event such as a supernova, but seeing a signal repeat over and over has steered them away from such a suggestion.

By using a large network of radio telescopes, FRB 121102 was discovered to be coming from a dim dwarf galaxy some 3 billion light years from Earth. Further studies then discovered that it was in the midst of a compact star-forming region, which led to the suggestion that the source was a strongly magnetised neutron star that had only recently formed.

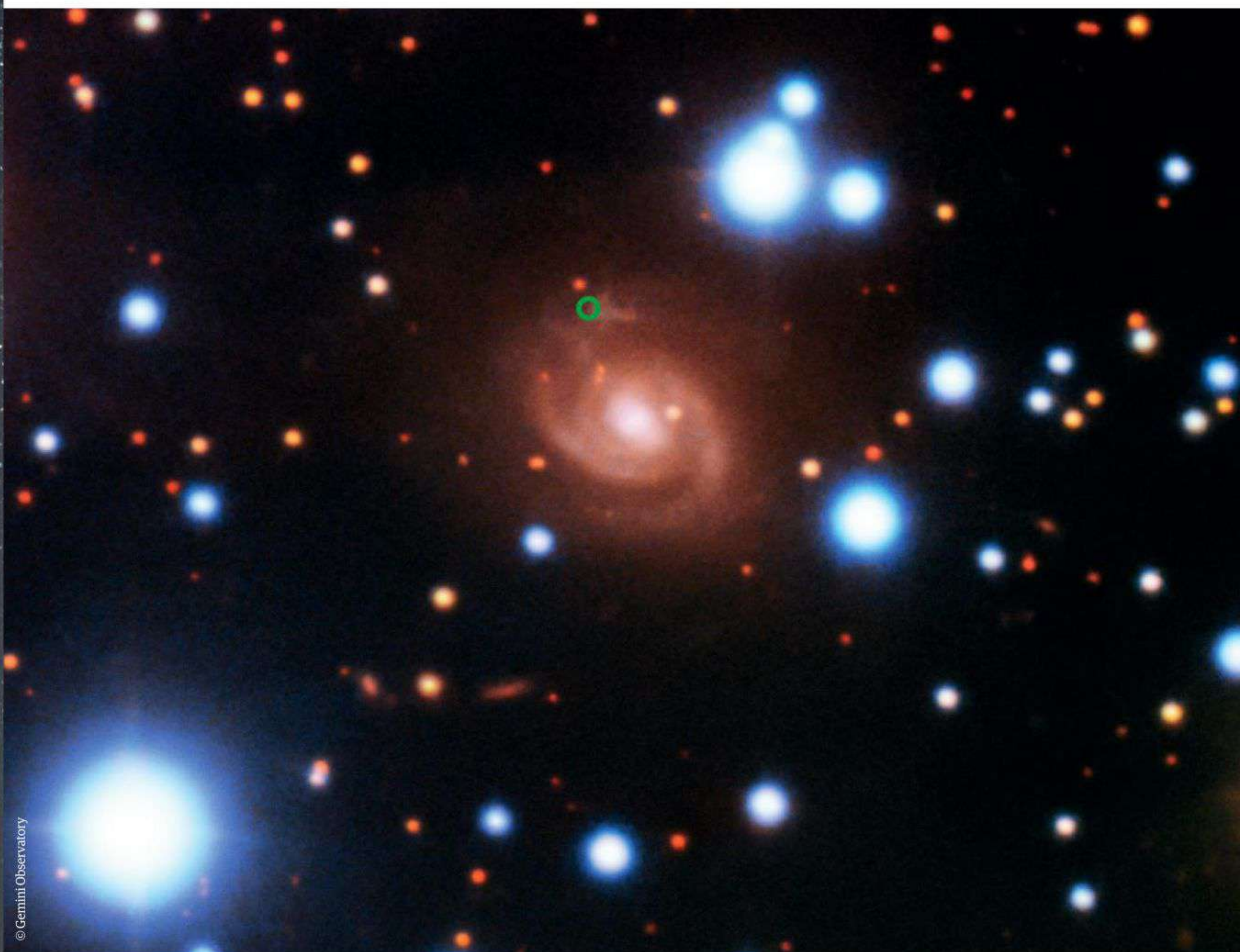
Late last year, however - and following the emergence of a couple more repeating FRBs - a further discovery was made which forced astronomers to once again reconsider their theories. This time around researchers were

looking at data from the Canadian Hydrogen Intensity Mapping Experiment Fast Radio Burst Project (CHIME/FRB), and what they saw made jaws drop across the world.

Focusing on a fast radio burst - which became known as FRB 180916.J0158+65 - between September 2018 and October 2019, the researchers traced back 400 observations. In doing so they not only noted a steady beat, but a regular, cyclic pattern that had never been seen before. It showed that the FRB would be active for four days, releasing a burst or two every hour. It would then fall silent for 12 days before starting up once again.

In total the entire cycle was seen to last 16.35 days, and it repeated like clockwork over some 28 bursts. There were periods when it didn't awaken or only emitted a single burst, but this is likely because CHIME/FRB was not able to keep an eye on the FRB at all times. "The pattern told us that the repeating FRBs have an underlying periodicity," says Lorimer. "I wasn't expecting to see a periodicity in burst activity."

Such repetition has made it easier to trace this particular FRB's origin, and it has been tracked back to a massive spiral galaxy that is about 500



million light years away. Scientists are able to figure out the distance by looking at the difference in arrival times between the FRB's faster arriving shorter frequency radio wavelengths compared to the longer ones. This is called the dispersion measure, and the delay indicates the interaction with electrons - the more matter travelled through, the greater the distance.

Using this, FRB 180916.J0158+65 was shown to be seven-times closer than FRB 121102. It is also much closer than two non-repeating FRBs which scientists have managed to successfully track - one of these was detected in 2019 using an array of 36 satellites called the Australian Square Kilometre Array Pathfinder telescope, placing it within a galaxy roughly the size of the Milky Way 3.6 billion light years away from Earth.

"[FRB 180916.J0158+65] is among the closest yet seen, and we even speculated that it could be a more conventional object in the outskirts of our own galaxy," said Mohit Bhardwaj, study co-author and McGill University doctoral student, in a written statement at the time. "However, the observation proved that it's in a relatively nearby galaxy, making it still a puzzling FRB but close enough to now study using many other telescopes."

That is certainly taking place right now, but Lorimer says the location source of FRB 180916.J0158+65 is of great interest for other reasons. "It shows that FRBs might be detectable in our Milky Way as well because it's in a spiral galaxy like our own," he says. It is also intriguing that FRBs are being picked up at low frequencies - FRB 180725A was detected as low as 580 MHz in 2018, the first to be detected under 700 MHz.

What, however, is creating the repetitive pattern seen in FRB 180916.J0158+65, and what is the source of FRBs in general? The simple answer is that there is no conclusion that can be reached with any great certainty right now, particularly because we're seeing host galaxies for FRBs that are different to each other.

In a paper published to the arXiv database, the researchers say that existing explanations for FRBs do not fit. The discovery of a 16.35-day cycle is crucial, however, because it at least provides a clue about the nature of the object.

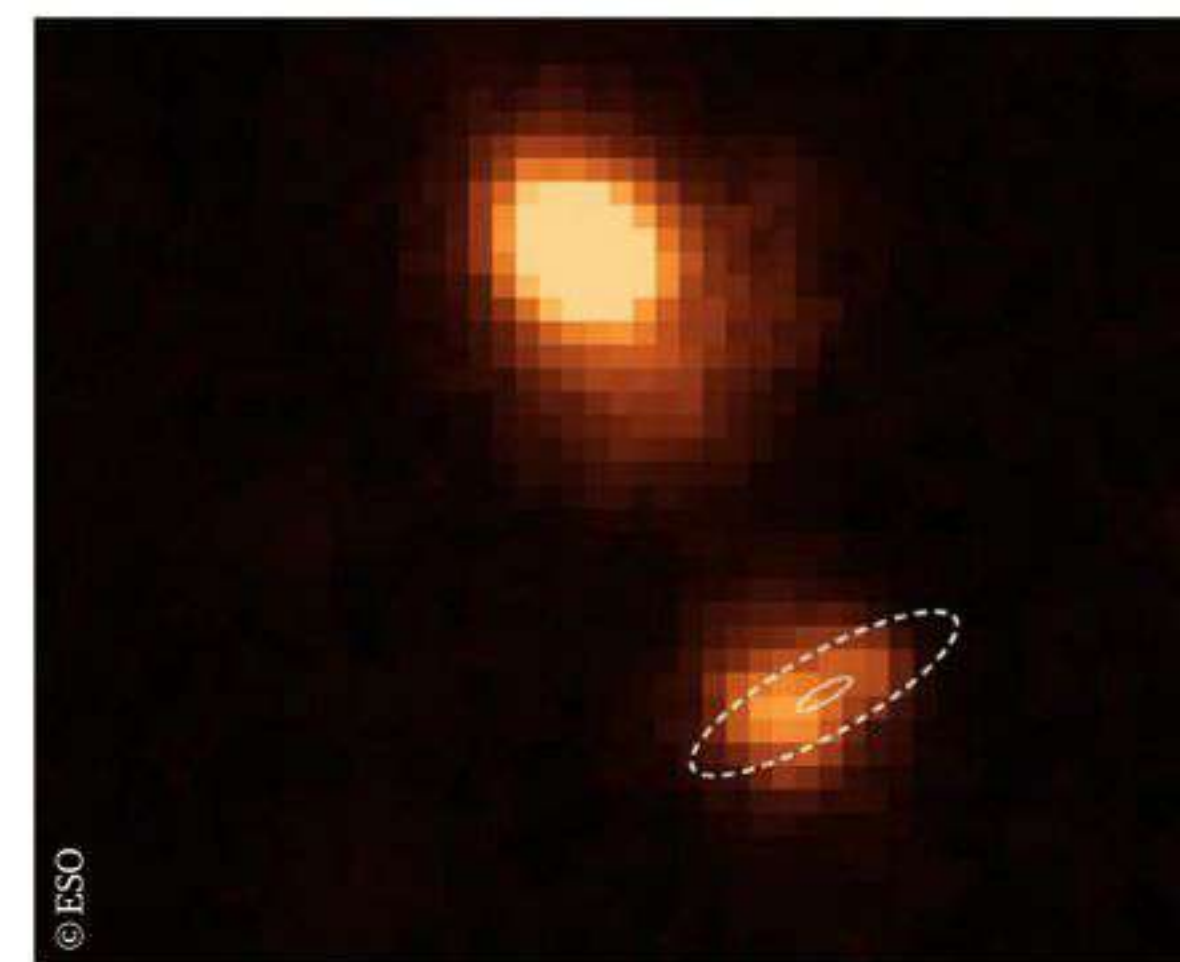
"If confirmed this could be a highly important discovery," says Professor Maxim Lyutikov of Purdue University, pointing to a couple of possibilities. On the one hand, he explains, the periodicity could be intrinsic to the FRB. "In a sense it would be an essential part of the central engine," he tells us. "But it could also be an external property which is not essential for the functioning of the engine. In the latter case, it still tells us something about the source - that it is in a stellar-mass binary - but not how the source manages to produce the bursts."

In order to try and get to the bottom of this ongoing mystery, Lyutikov has co-authored a

Top: Artist's impression of FRB 181112 reaching Earth from its source in space - it is believed to have passed through the halo of an intervening galaxy

Bottom left: When the FRBs appeared to be one-off bursts, they were determined to have resulted from a single cataclysmic event

Bottom right: ESO's Very Large Telescope sought to determine the distance of FRB 181112 (ringed in white) from its host galaxy



HOW DO FAST RADIO BURSTS WORK?

Many subscribe to a theory put forward by Brian Metzger, a theorist at Columbia University

1 A big burp

This model suggests a powerful magnetic neutron star releases an occasional flare of charged particles.

2 Hitting debris

The flare travels at the speed of light and collides with clutter surrounding the magnetar left behind by previous flares.

3 Creating a shock wave

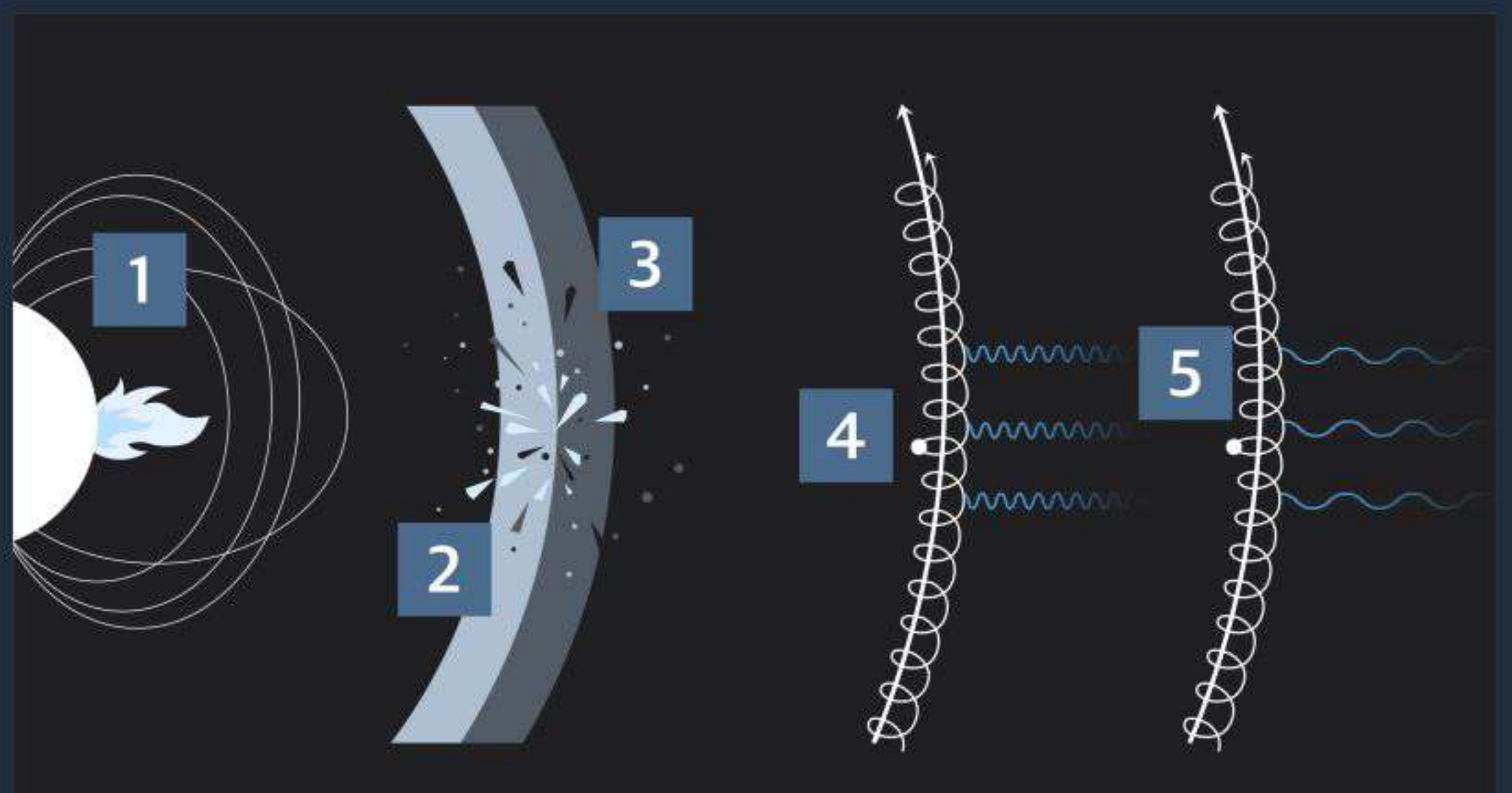
As a consequence of this impact with the slower moving surrounding ion cloud, shock waves are created.

4 Pushing outwards

This strengthens the magnetic field lines of the clouds, with the electrons gyrating as the shock wave pushes out.

5 Sending signals

The effect of this motion is a burst of energetic radio waves that eventually slow to a lower frequency.



TUNING INTO THE SKIES

Cutting-edge telescopes are being deployed in the hunt for more fast radio bursts

1 Five-hundred-meter Aperture Spherical Telescope (FAST)

As the largest single-dish radio telescope in the world, FAST was able to detect even the faintest of bursts from the FRB known as 121102. Located in Guizhou in southwest China and costing \$180 million (£140 million) to build over five years, it has been built into a natural crater in the ground, suspended by six cable-support towers and a network of 7,000 steel wires. It offers twice the sensitivity of the next-largest telescope while being ten-times faster than anything previously built, focusing radio waves from its fixed primary reflector on an antenna that is 140 metres (460 feet) above it. Able to work within a frequency range of between 70 MHz and 3.0 GHz, it's an ideal telescope in looking for radio emissions from stars and galaxies deep in space. But as well as being used to observe distant pulsars and survey neutral hydrogens, it will also be looking for signs of alien life.

2 Australian Square Kilometre Array Pathfinder (ASKAP)

Rather than creating a single large radio telescope, ASKAP makes use of 36 parabolic antennae spread across the outback in western Australia. The array works as a single instrument that can offer a collecting area of 4,000 square metres (43,056 square feet), and it has played an important part in the discovery of fast radio bursts in recent years. Key to this has been an extremely wide field of view of 30 square degrees that can be expanded to 240 square degrees by pointing the antennae in different directions. It has also helped that astronomers have developed a way to freeze and save the data they collect within a second of a burst being discovered so that the location of the source can be pinpointed. ASKAP is seen as a precursor to the larger Square Kilometre Array project that will be installed in both Australia and South Africa. This ambitious project will make use of thousands of dishes and as many as a million low-frequency antennae.

1

3

3 Canadian Hydrogen Intensity Mapping Experiment (CHIME)

Consisting of four trough-shaped antennae made of a reflective metallic mesh, this interferometric telescope is located at the Dominion Radio Astrophysical Observatory, and it has worked hard in the global hunt for new FRBs. While it may not be as powerful as its rivals and was actually created to explore the early universe, it's well-suited to conducting highly sensitive surveys of the night sky, receiving its radio waves from hydrogen and at frequencies within the range of 400 and 800 MHz and boasting a mapping speed that is largely unrivalled. It was this telescope which discovered the second repeating FRB to be observed, 180814, as well as the curious cyclic repeater FRB 180916.J0158+65. That is expected to be just the start, since CHIME is capable of far more frequent – even daily – discoveries. It can quickly process the data it receives using Intel Xeon E5-2630 processors coupled with 128GB of RAM, cleaning away noise and giving astronomers much to ponder.

paper which suggests the FRB is due to a binary star system comprising a massive star and a magnetar, which is a type of very young - decades old - neutron star with a powerful magnetic field.

"The observed periodicity of 16.35 days is mostly consistent with a tight stellar-mass binary," he argues. "The orbital separation would be similar to the Earth-Sun case."

In Lyutikov's explanation he points to both the source of the FRBs - presumably a neutron star - and the source of the companion - presumably a hot, massive short-lived OB star - producing winds. "If the wind of the companion dominates over the pulsar's wind, the pulsar's wind is confined to cavity, behind the pulsar. When radio bursts from the neutron star propagate straight into the companion's wind,

they are absorbed," he adds. "While for some orbital phases the radio waves first propagate in a long, nearly empty cavity - the confined pulsar wind - when the radio waves finally exit the pulsar wind and start interacting with the companion's wind at the far end of the cavity, the density for the companion's wind is much lower, and the radio waves suffer less absorption."

Under Lyutikov's model - the underlying idea being that the signals from the FRB source are interrupted by the companion - the periodicity is not due to the spin of the neutron star, but due to the orbital motion. This is also a shared hunch of Lorimer, who tells us: "My suspicion is that it is due to orbital motion. The source could be obscured for some fraction of the orbit, for example."

And yet, while many other scientists agree that the FRB is likely in a binary system with some other object, they are not always on the same page when it comes to what that secondary body could be. One thing's for sure,

the odd pattern raises interesting questions. "My thinking was that the arrival times between the pulses themselves are periodic, but this seems quite different," Lorimer continues.

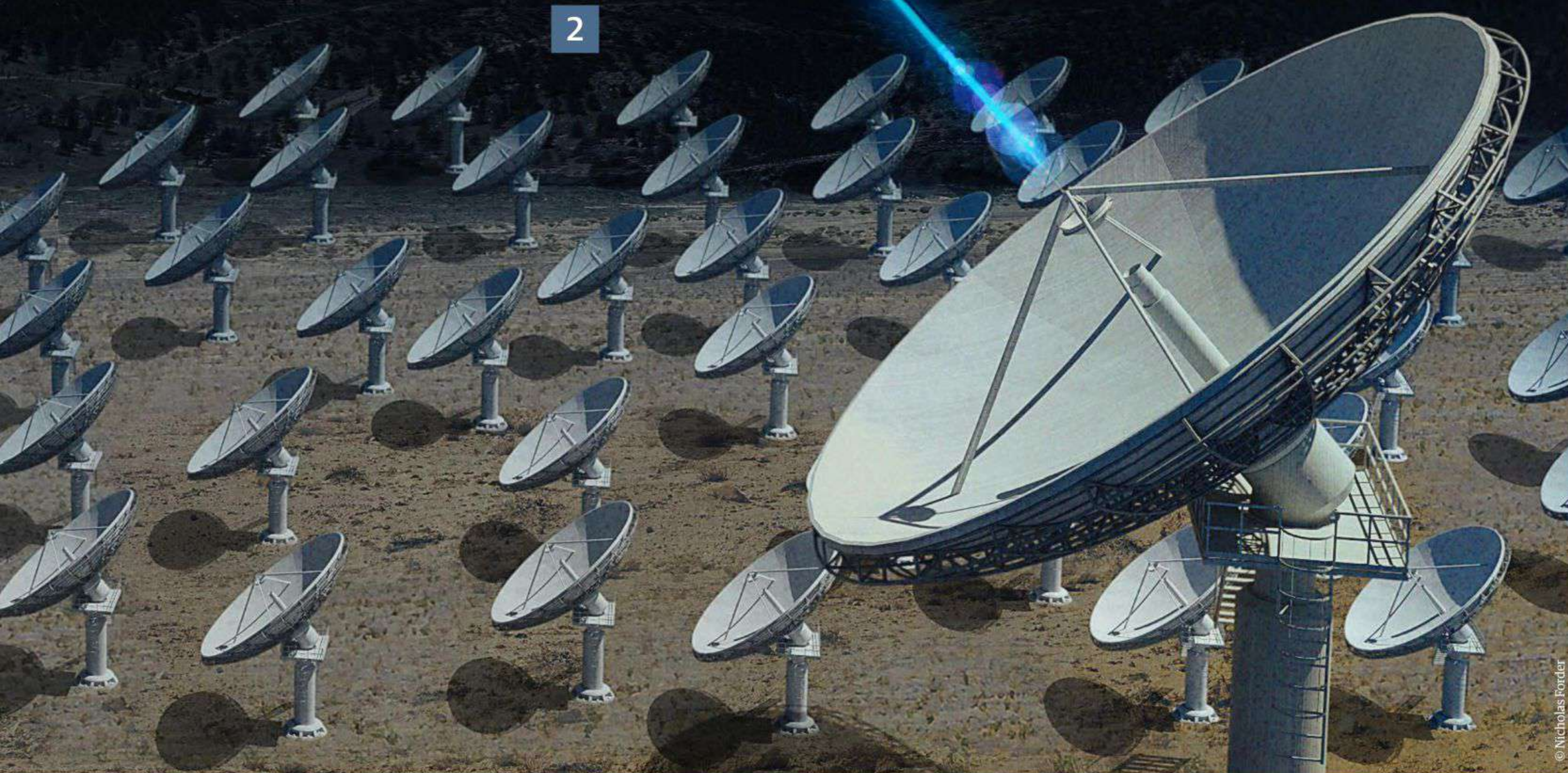
In his view, "obscuration by a cloud of gas in the orbiting system could account for the period of inactivity between the regular bursts". A binary explanation also seems more likely, perhaps, than the FRB being a single unstable or rotating object, although nothing can be taken off the table as yet. "At the moment we do not have a smoking gun that clearly indicates the nature of FRBs, so all possibilities should be considered," Loeb says.

Indeed, according to Loeb, FRBs are the bright analogues of pulsars - those spinning neutron stars with strong magnetic fields - and this was an idea he explored in a recent paper. "The duration and radio frequency of FRBs are similar to the flashes from pulsars, but they are intrinsically billions of times brighter and more sporadic. As a result of them being so bright, we can see them from the edge of the universe, whereas pulsars are detectable only within the Milky Way galaxy."

Above:
The Parkes
Telescope in
Australia was
used to detect
the very
first FRB



2



He says his guess is that "the periodicity originates from an orbit around a companion star or some long-term precession of the radio beam," adding that "we observe periodicity in many astrophysical systems such as pairs of stars". But he also tells us that it's possible FRBs are a mixed population with a variety of source types and that we cannot even entirely rule out artificial origin - an alien theory which has already gathered some traction in the popular press. But is he serious? "By itself, periodicity is not unusual enough to require an artificial origin," he counters, playing down the possibility. "If we detected a Morse-coded message then the data would have required a more creative interpretation, but it's unlikely this signal is being used for communication because of the large time delays associated with a dialogue across large distances."

"If the communication was aimed for short distances then the beacon of light would not

have been so powerful, to save energy. Instead a civilisation might generate a powerful beam of light to propel cargos with a sail, and we could observe the leakage of that radiation outside the boundaries of the sail. This is an idea on which I wrote two papers."

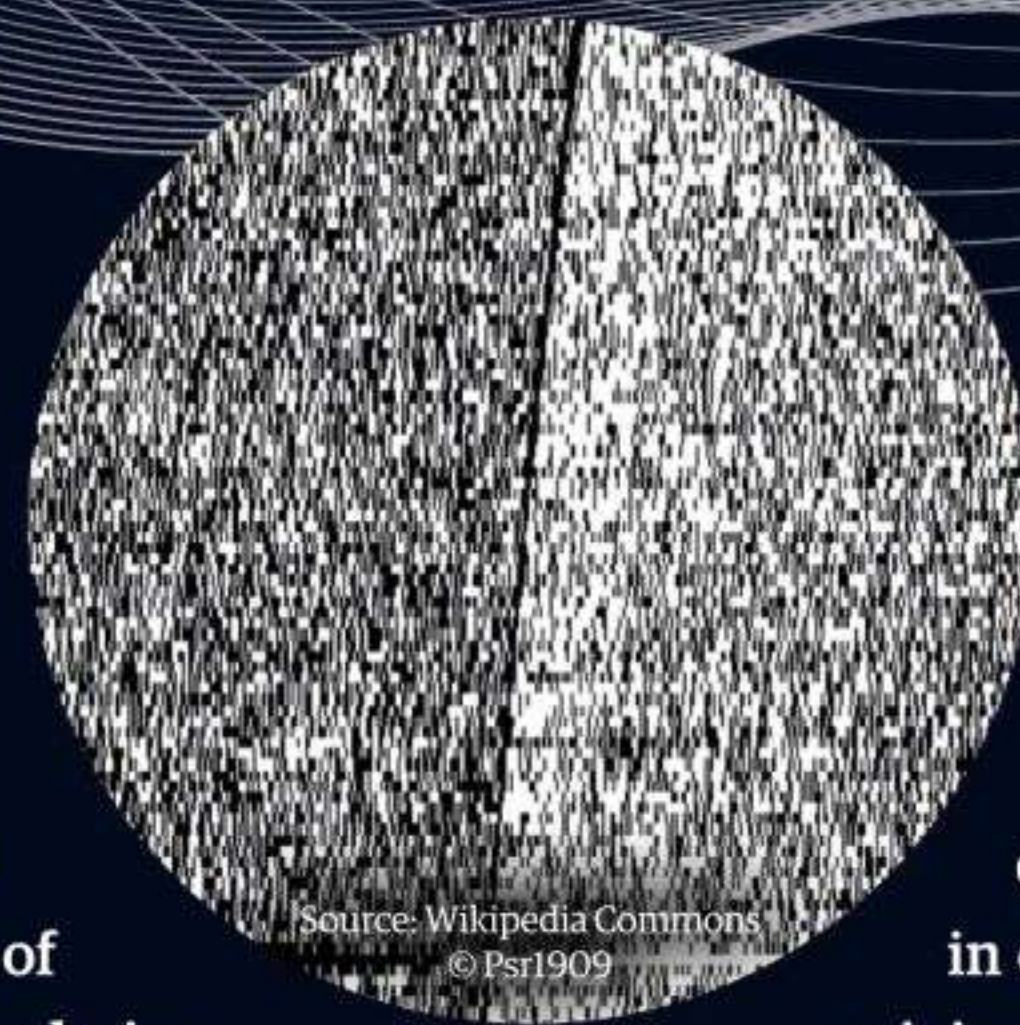
In one of those papers he shows that in order to produce FRBs across cosmological distances, you would need to use a huge amount of power, comparable to the total power in sunlight intercepted by the Earth. "This would require a vast engineering project, millions of times more ambitious than we ever contemplated here on Earth. The main technological challenge is in the enormous amount of power that the radio beam needs to carry."

Given that, breakthroughs will need to be made in other ways. "One way to identify the

nature of FRBs is to discover a nearby repeating FRB that is very bright, so that we could study its environment in great detail. Another breakthrough in our understanding could

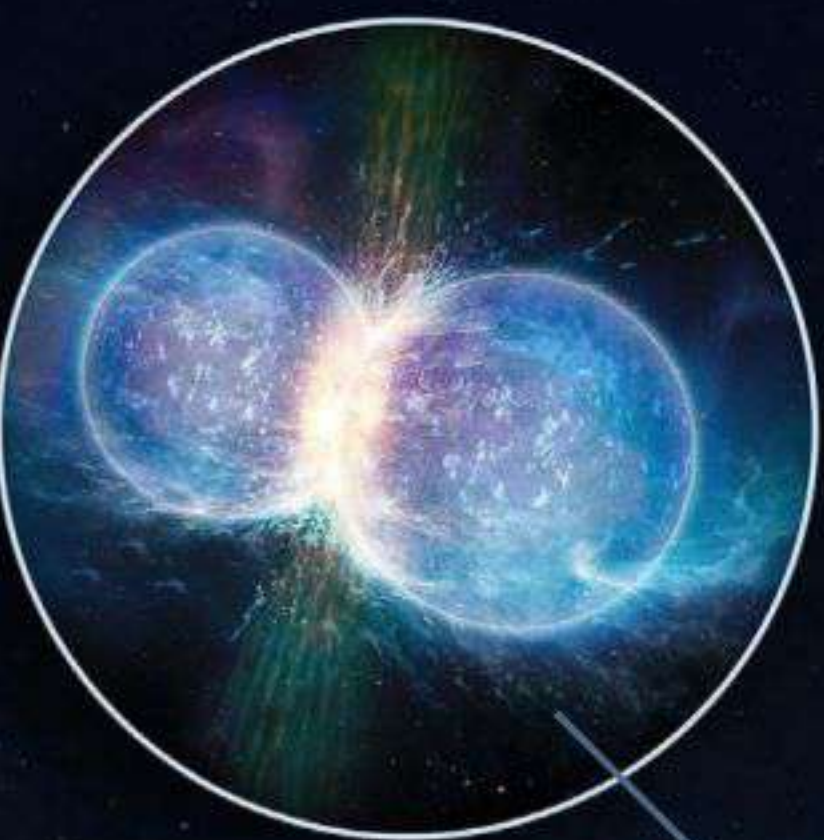
originate from detecting FRBs at other wavelengths in addition to radio. This could provide an important clue about the nature of their central engine."

This means the studies will be continuing for many more decades, with each new discovery raising ever more questions. "I think it's quite possible that there could be more than one class of FRB: repeating versus non-repeating. We know that gamma-ray bursts come in two different varieties, so there is certainly a precedent for this. I still think it is very early days but, if confirmed, repeating FRBs might all share a periodicity. That is something that needs to be carefully studied over the coming years."



THE THEORIES

What could the source of the bursts possibly be?



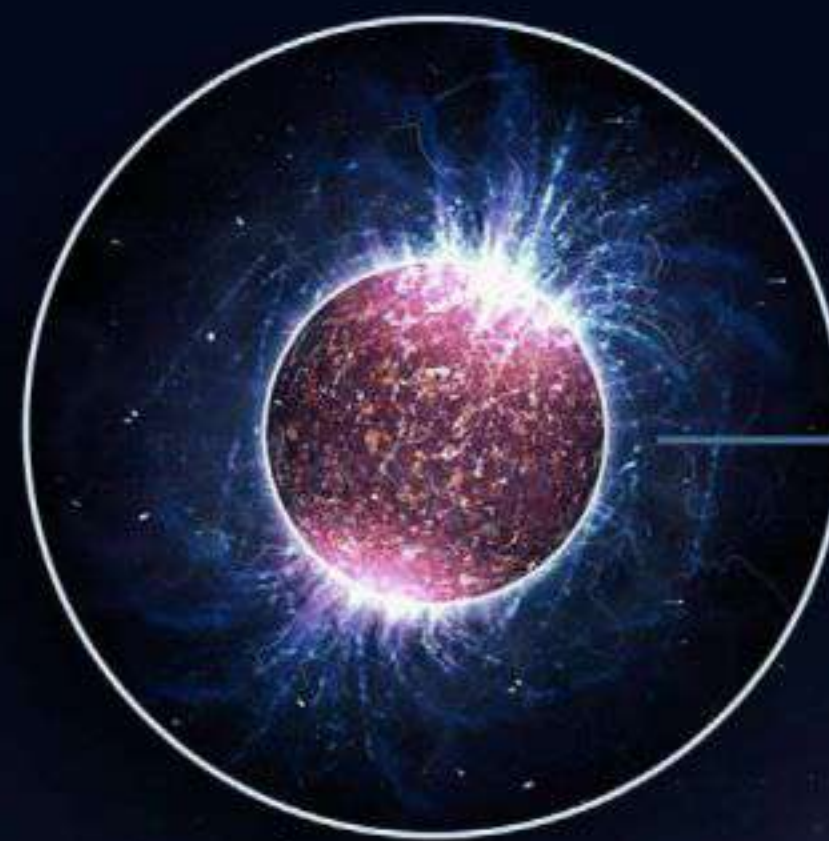
Flares emerging from a stellar collision?

When FRBs were first discovered in 2007, they were not seen to repeat. Scientists considered that the single flashes they were observing may be due to a sole cataclysmic event such as the merging of a couple of neutron stars. This theory becomes a problem when you begin to take into account the repeating FRBs.



An alien message

Proponents of this argument point to the repeating patterns of 180916.J0158+65 and say it could be a form of communication, or at the very least radiation leaking from an alien ship. But these are all over the sky, so aliens would have to organise vast swathes of the universe to engage in such a mass broadcast.



Magnetic neutron star?

Scientists have discovered evidence of dim-yet-steady sources of nearby radio emission. They have also been able to track back FRBs to dense regions of plasma which have extreme magnetic fields. This has led to a theory that the FRBs are due to young neutron stars called magnetars burping out charged particles that go on to power persistent radio emission.

Above: Duncan Lorimer detected the first radio burst in 2007, and it became known as the Lorimer Burst

© Nicholas Forster

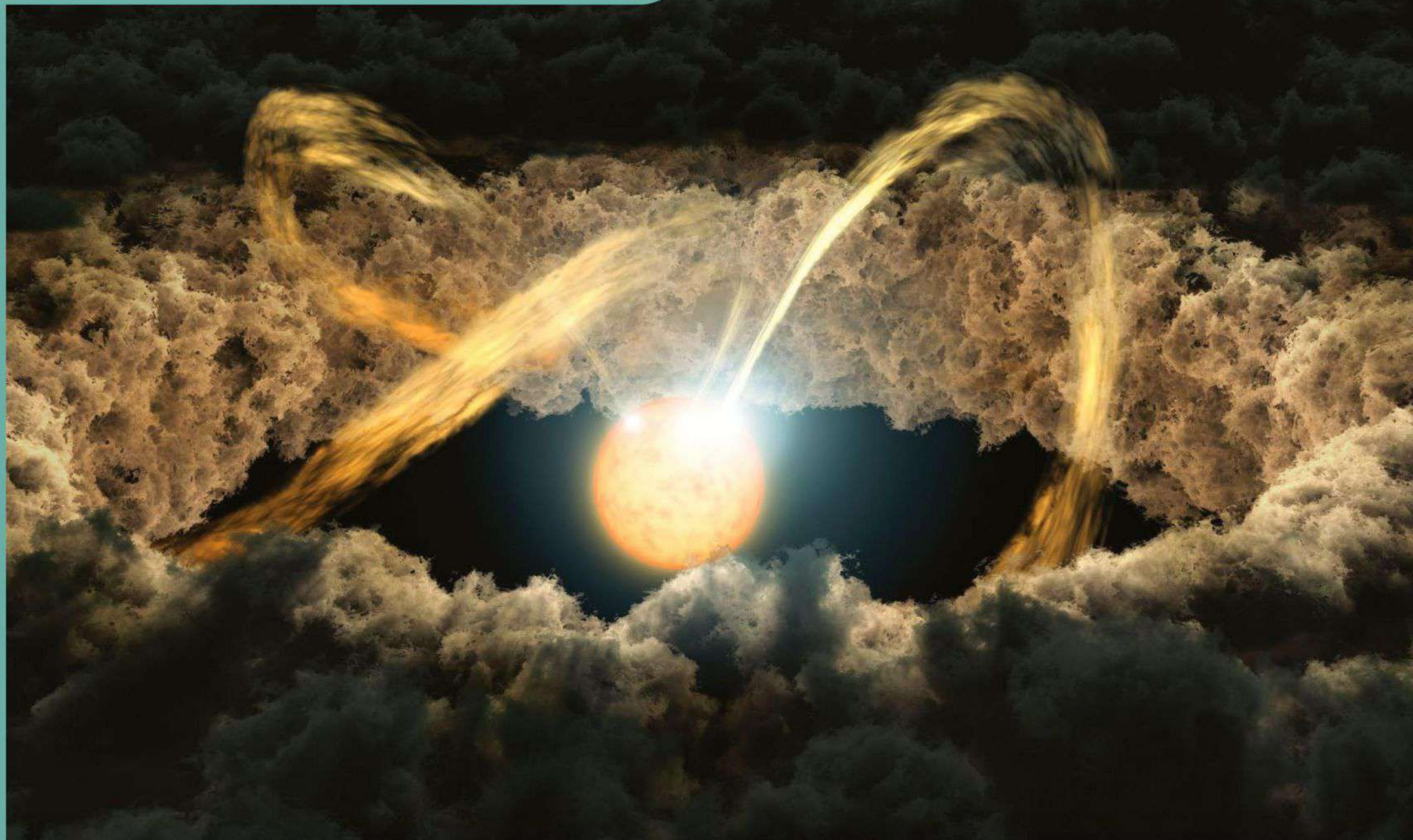
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EXOPLANETS

Do smaller stars generally host smaller planets?

The Sun is a typical star, but many smaller stars exist in the universe. Red dwarfs are the smallest stars, measuring about 10 to 50 per cent the size of the Sun. Over the past two decades, many planets have been detected around such red dwarf stars. Surprisingly, these worlds are not much different from those found around Sun-like stars. Many of them are rocky, Earth-like planets, like, for example, the seven planets detected around the TRAPPIST-1 star and the two planets around Proxima Centauri, the closest star to the Sun.

On the other hand, a significant fraction of them are large, gas giants like Jupiter. In fact, some red dwarf stars host planets ten times as big as the king of the Solar System yet how these worlds form remains an unsolved mystery since

these small stars do not have enough material in the discs around them to form such big planets.

However, it is possible that their discs had much more material when these stars were very young. If this is the case, then these big discs would fragment - in other words break up into pieces - due to their own gravity, and quickly form giant planets.

Hopefully future observations of the atmospheres of such planets from dedicated space telescopes - like the James Webb Space Telescope due to be launched in March 2021 - will reveal chemical signatures of their formation mechanisms.



Dr Dimitris Stamatellos is an associate professor at the Jeremiah Horrocks Institute

Above: Planets form from the constant accumulation of material during a star's young years

SPACE EXPLORATION

How much does it cost to send someone into space?

A good question! The answer depends on how you get there, who is paying and which costs you consider.

There have been different ways to get to and from the International Space Station (ISS) over the years: the now-retired American Space Shuttle, the Russian Soyuz spacecraft and soon Boeing's Starliner and SpaceX's Crew Dragon. The costs vary, but the cost per seat is in the region of about £50 to 69 million (\$65 to 90 million).

Once you are in space though, you need somewhere to stay, and that's the Space Station, so you need to factor those costs in too. The ISS has cost about £77 billion (\$100 billion) since the first plans were drawn up around 30 years ago.

This money, however, isn't being spent in space. It's buying the time and expertise of the many tens of thousands of people needed to design, build and operate the ISS, which hosts hundreds of scientific experiments every year. For the ISS, these costs are shared between all the international partners that make up the programme, and the UK contributes through the European Space Agency (ESA).

The European Space Agency doesn't buy a



flight ticket with money, but instead exchanges contributions to the Space Station, and in return NASA flies ESA astronauts.

The money that the UK contributes to the European Space Agency comes back to the country in the form of business for a variety of UK companies, which in turn helps grow those companies and the British economy.



Libby Jackson is the human exploration programme manager at the UK Space Agency

"The cost per seat is in the region of about £50 to 69 million"

Libby Jackson

SOLAR SYSTEM

Why does Jupiter have different coloured bands?

The coloured bands of Jupiter have been a subject of great fascination for centuries. The light stripes are called zones, while the dark ones are belts. These bands are driven by powerful atmospheric flows that travel in opposite directions at speeds reaching some 540 kilometres (340 miles) per hour.

We know from space probes and telescopic observations that the temperature and the composition of the zones differ from that of the belts. For example, zones are colder, which corresponds to gas upwellings, and are rich in frozen ammonia, hence their colour. Belts are hotter, which means that the gas flow is downwelling. Despite decades of research, it is still not clear which chemicals make these belts up.

Two main frameworks compete to describe their origin. First that they are generated by deep internal convection, a process where the motion of the gas transfers heat. Since Jupiter's atmosphere and interior are connected, the zonal flows would extend substantially into the conducting hydrogen core. Second is that they are surface phenomena, primarily maintained by the aforementioned temperature difference between the zones and belts. Recent data suggests the former, which if confirmed, would be an amazing revelation. Think of hurricanes the size of Earth that run thousands of kilometres deep into the metallic hydrogen core.



Dr Mohamed Zaghoo is a research associate at the University of Rochester, New York

Above: There are a variety of costs that go into an astronaut's journey into space

Right: The zones and bands of Jupiter have been a mystery to astronomers ever since the telescope was first invented

Did you know?

The Great Red Spot is a famous bright-hued Jovian storm which has been observed continually since 1830.



HUNT FOR LIFE

What is the cosmic gorilla effect?

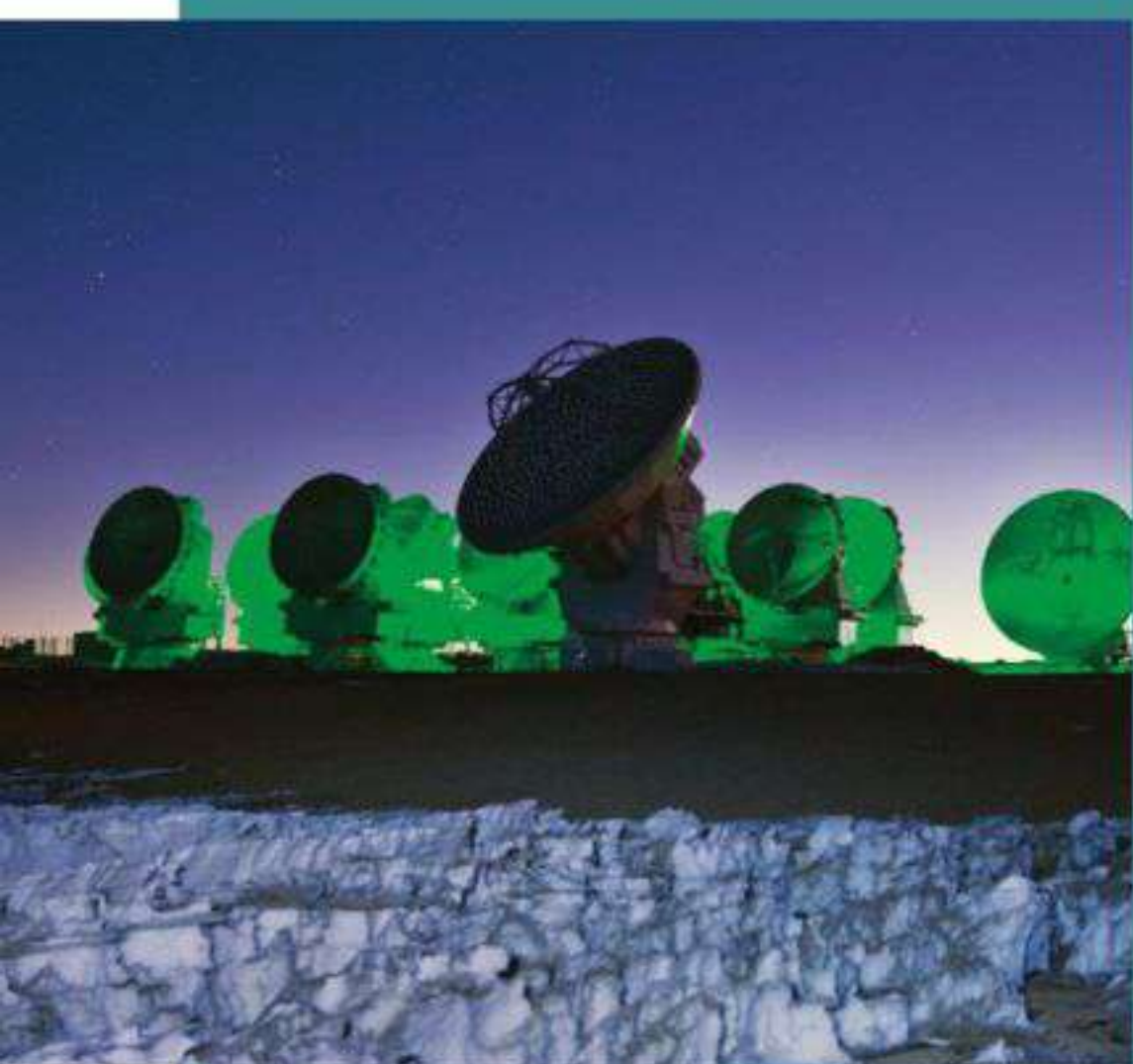
The 'cosmic gorilla effect' refers to a cognitive event inspired by the original experiment carried out by the researchers Christopher Chabris and Daniel Simons in the 1990s to show the inattentional blindness of the human being.

In the experiment, a boy in a gorilla costume could walk through a scene while the observers were preoccupied, and more than half did not notice. The cosmic gorilla represents this same effect in relation to the search for extraterrestrial intelligence – we can be so focused on trying to find a certain type of signal relating to extraterrestrial origin that we might miss the 'gorilla' in the room: in other words, other types of evidence.

This can be due to three possible factors. First, due to limitations of our physiology and consciousness development. Second, the wrong technological approach – for example, using mainly radio signal detection in detriment of other types. And third, intentional avoidance by extraterrestrial intelligence.

This experiment has potentially revolutionary implications because our consciousness may be mediating and conditioning the task itself, as well as the results.

Dr Gabriel De la Torre is
assistant professor
of psychology at the
University of Cádiz



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SPACE EXPLORATION

Could there be another Space Race?

I believe we're already seeing another Space Race, except that instead of states racing to the Moon, it's a commercial space race among private entrepreneurs like Elon Musk's SpaceX and Jeff Bezos' Blue Origin. Both have been inspired by somewhat different visions of humanity's future in space and are investing heavily in the technology to make that happen. Launch costs have come down dramatically as these companies have developed reusable rocket technology. As launch costs drop further, more people, countries, companies and scientists can access space than ever before, with yet-to-be-seen benefits. Seeing the possibility for not just economical access to space, but economic benefits, many companies are now racing to see who can make space profitable.

With greater access to a limited resource comes greater congestion and competition. For most of the space era, states have utilised it for military and strategic advantage, and as more countries seek to use space, there might also be a military space race in the offing. While I believe the rhetoric is a bit overblown, racing doesn't have to be negative; the original Space Race led to technological breakthroughs that we take for granted today. New space races will undoubtedly result in discoveries and opportunities and provide a basis for increased cooperation in the future amongst technological equals.



Dr Wendy Whitman Cobb is a professor at the
School of Advanced Air and Space Studies, Alabama



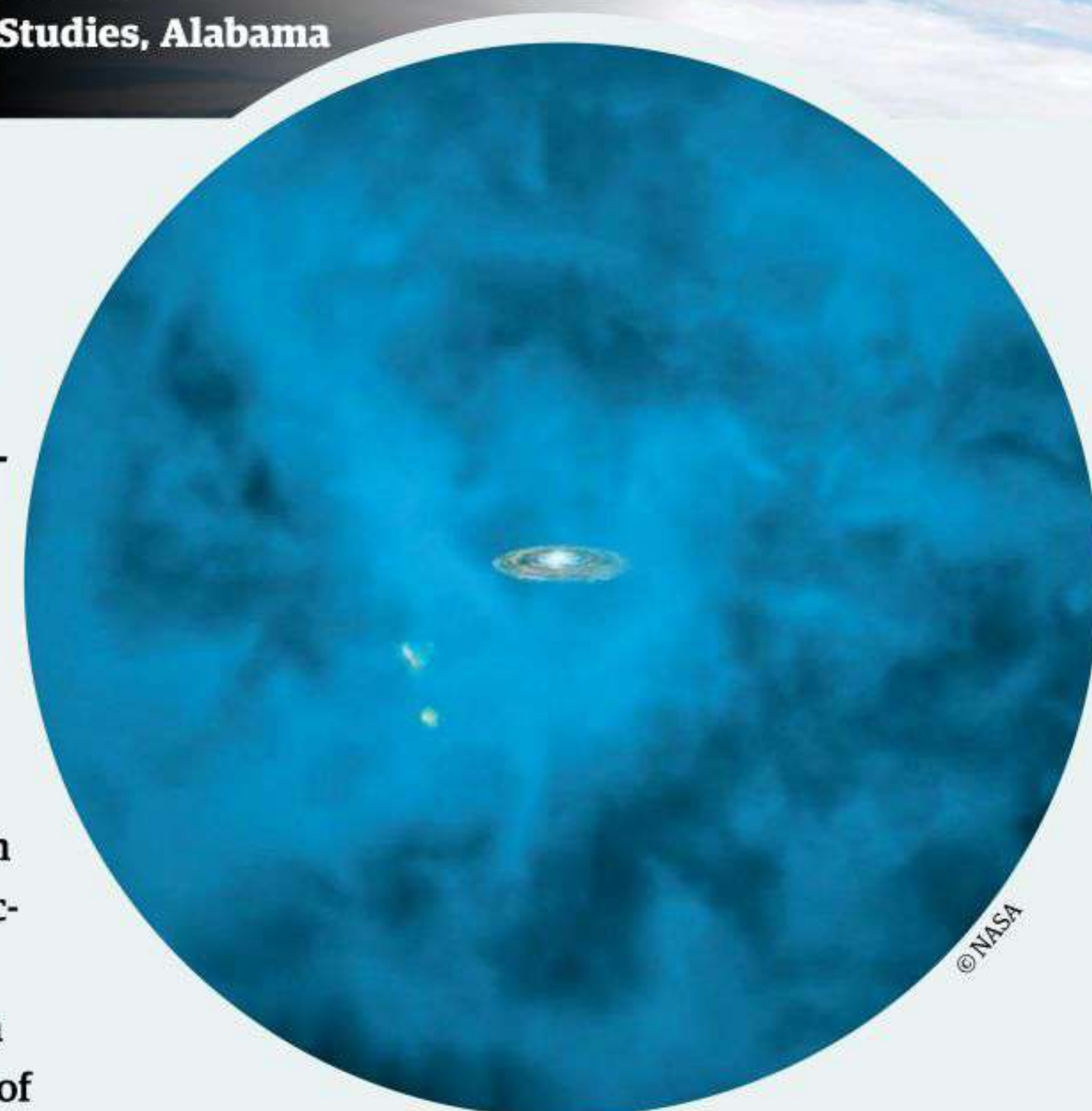
ASTROPHYSICS

What is the circumgalactic medium?

When we think about galaxies, we think about the beautiful pictures of stellar discs that we have seen in the media. They often show grand-design spiral structures with bright-blue stars. Our own galaxy, the Milky Way, is also believed to be a spiral structure in which the stars are arranged in a circular, disc-like structure.

The galactic disc sits in a much larger and a much more massive spherical 'halo'. The size of this feature is more than ten times the size of the disc and its mass is about 15 times the 'weight' of the stellar disc. The halo is made of 'dark matter'; currently we do not know what this dark matter is, but it is believed to be made up of some subatomic particles.

The halo is also filled with gas. Since this gas surrounds the disc made of stars, it is called the circumgalactic medium, which contains gas at a range of temperatures from several thousand Kelvin to several million Kelvin. At thousands of Kelvin, atoms are either neutral or mildly



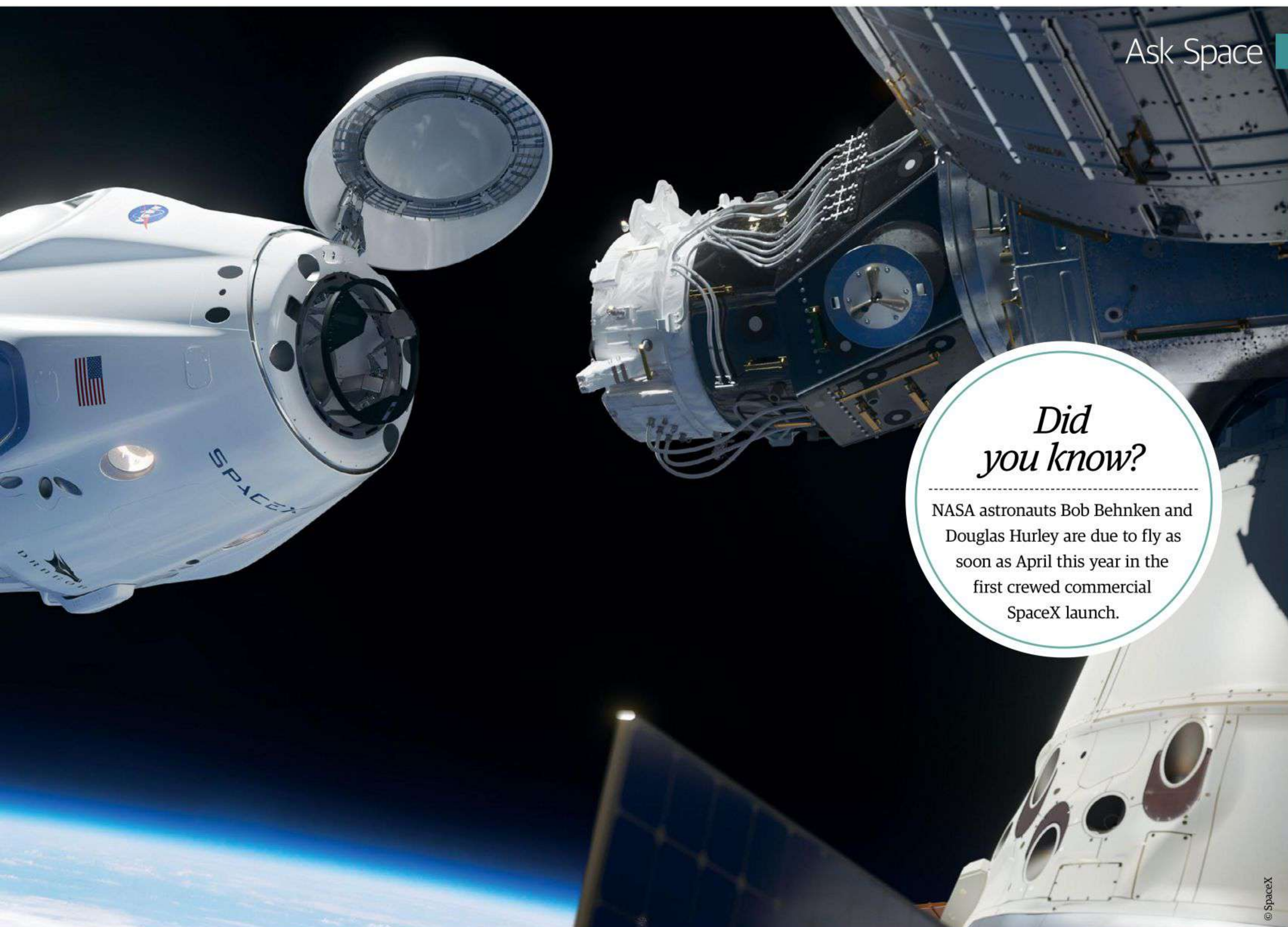
© NASA

ionised. At hotter temperatures, more and more atoms get more and ionised (they are stripped of some electrons).

Theoretical simulations tell us that most of the gas in the circumgalactic medium is hot, at millions of Kelvin. Observations of such hot gas are carried out with space-based X-ray telescopes like the Chandra X-ray Observatory and the XMM-Newton Observatory.



Professor Smita Mathur is a professor
of astronomy at Ohio State University



Did you know?

NASA astronauts Bob Behnken and Douglas Hurley are due to fly as soon as April this year in the first crewed commercial SpaceX launch.

MOONS

Why are there no gas moons?

Of all the moons in this Solar System only one, Titan, has an appreciable atmosphere. But even Titan is mostly made of rock and ice, which doesn't constitute it as a 'gas moon'. In contrast, planets like Jupiter and Saturn are made mostly of hydrogen, with the primordial gas making up 90 and 94 per cent of their respective compositions. This is the reason why they are regularly referred to as 'gas planets'.

The early Solar System contained lots of hydrogen, but because the gas is very light, only really large planets could hold on to it. Jupiter and Saturn began life as solid bodies and grew to about ten times the mass of the Earth. At that point they were able to capture and hold onto the hydrogen that permeated the young Solar System.

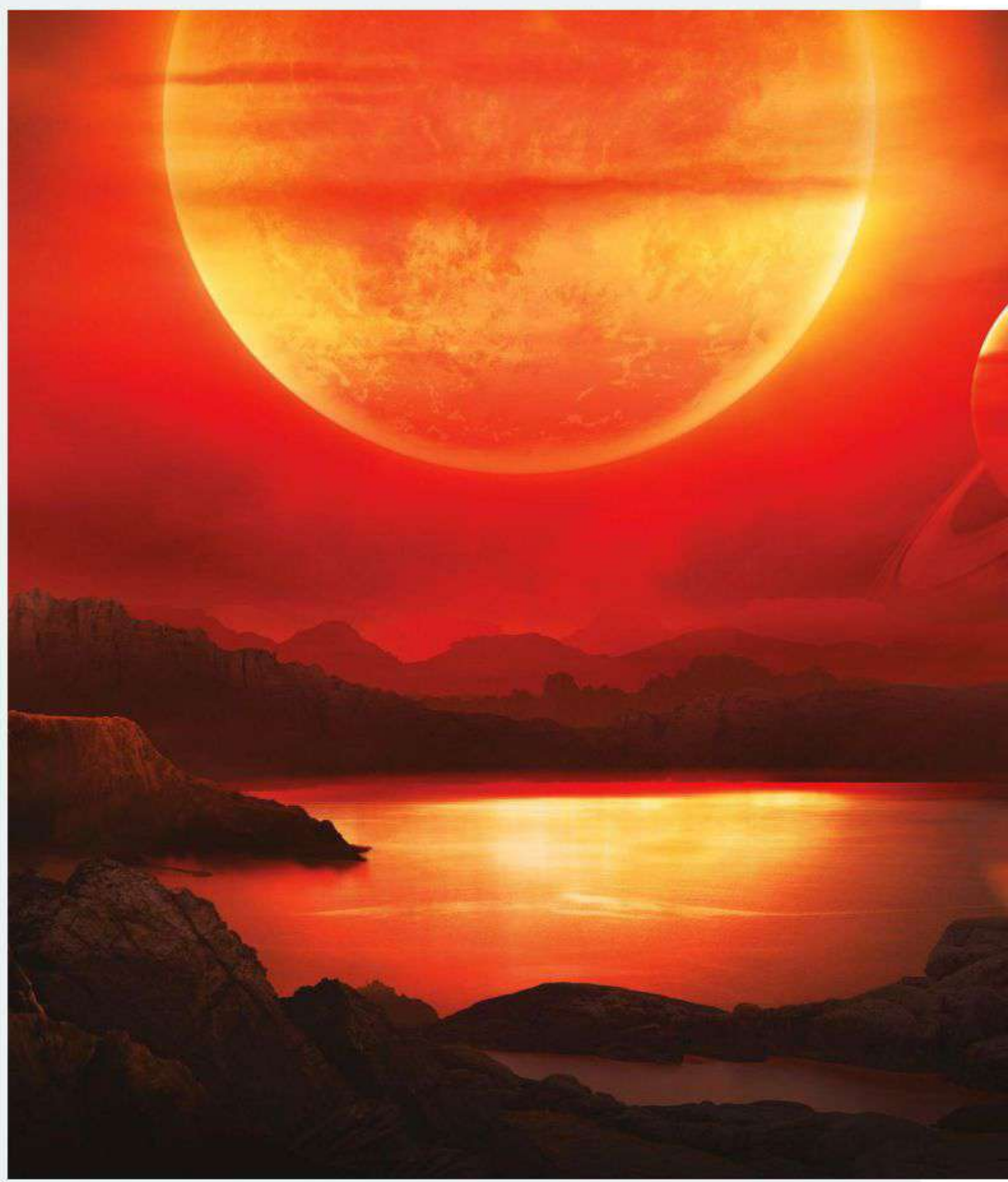
However, because none of the moons in our solar neighbourhood grew to a great enough size, none of them managed to capture any hydrogen. Titan successfully captured some heavier gases, which have given this moon its atmosphere. However, similar moons such as Ganymede and Callisto do not have an atmosphere, even though the former is bigger than Titan while Callisto is roughly the same size. The reasons why Ganymede and Callisto do not have atmospheres though are still unclear.



Professor Francis Nimmo is a professor in the department of Earth and planetary sciences at the University of California Santa Cruz

Above: SpaceX is one of the world's leading private aerospace companies spurring on the new space race

Right: Moons in the Solar System are mostly ice and rock, but none of them are mainly gas



© Tobias Roetsch

20 TIPS AND TRICKS TO HELP YOU FIND, PHOTOGRAPH AND FIGURE OUT THE AURORA BOREALIS

Written by Jamie Carter

If you've never seen the northern lights then you're missing out on one of astronomy's greatest sights. If you have seen them, you probably want to go again, perhaps to see a stronger display, or to photograph this beautiful result of the solar wind interacting with Earth's magnetic field.

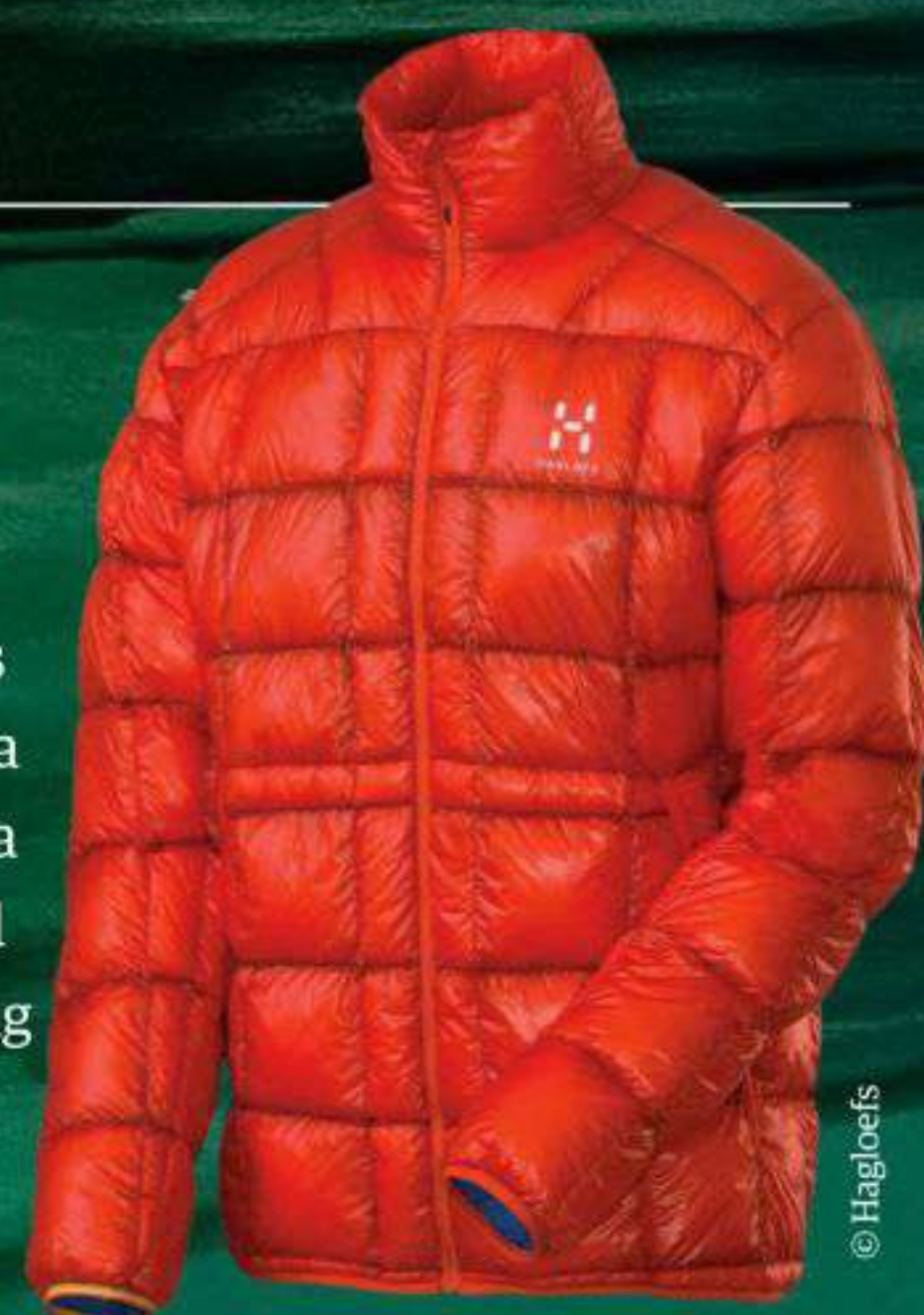
We've all heard from people who have travelled to see the northern lights, but return disappointed, perhaps being clouded out, or with some disappointing photographs. It's all about what you know, and when and where you go... and for how long. Choosing the right location at the right time of year, and even at the right time of month is critical, as is finding clear, dark skies. Luckily there are many organised trips to see the northern lights these days, whether they be dedicated cruises or escorted holidays, or merely a van tour with experienced staff who know how to find gaps in the clouds. Where do all those incredible photographs of the northern lights on social media come from? They come from people with relatively new cameras, which are becoming ultra-sensitive in darkness, who spend as long as they can in the Arctic Circle. Here's exactly how to maximise your chances of seeing one of nature's grandest spectacles.

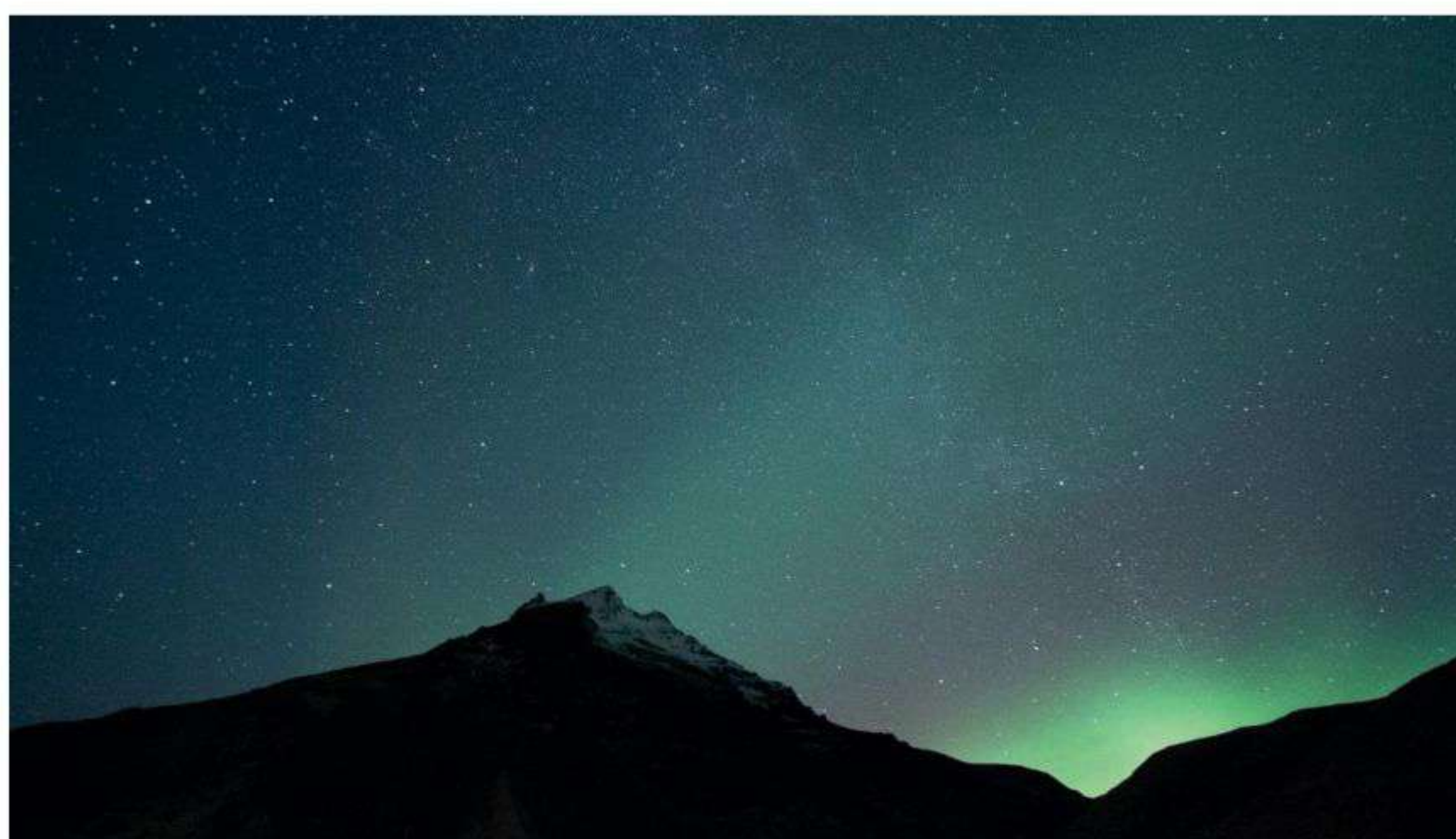
GET TO THE ARCTIC CIRCLE

1 The northern lights reliably occur at around 66 to 69° north latitudes, or thereabouts, so key locations include anywhere in Iceland, the Faroe Islands and Lapland, which encompasses northern Norway, northern Sweden and northern Finland. They can also be seen in Greenland, northern Russia, northern Canada and Alaska. They can occur south of the Arctic Circle, but not often.

WRAP UP WARM

2 Iceland is probably the warmest place to see the northern lights, thanks to its proximity to the jet stream, but wherever you go you should expect freezing temperatures and biting winds. Wrap up warm in a down jacket, fleece and base layers, a scarf, hat, seriously warm gloves and even a balaclava. Why all this? Seeing the northern lights demands cold, hard patience.





WAIT FOR DARK NIGHTS

3 The northern lights occur constantly, not only all year round, but all through the day and night. However, they are impossible to see unless it's dark. Since they occur at northerly latitudes, visitors should travel at times of the year when the nights are long and dark. That's why the viewing season is generally regarded to be between September and March, when darkness lasts 12 to 18 hours.



CHECK WITH THE MOON

4 You can see the northern lights during a full Moon, and for photographers the presence of strong moonlight can help in illuminating a lake, a mountain or some other geographical feature. However, it's best to aim for dark, moonlight-free nights. That means heading north in the week before a new Moon, and for a few days after.

FIND A DARK SKY

5 Lots of people head to Reykjavík in Iceland to see the northern lights, and although it's possible, it's far better to head out into the wilderness where the skies are much darker. That way not only will the phenomenon be brighter and more impactful, but your photographs will include something of the natural environment.



KEEP YOUR BOOTS BY THE BED

6 To maximise your chances, keep your boots by your bed and be ready to check the skies every hour or so throughout the night. Ignore anyone who tells you that they tend to appear at a specific time of night; there can be a powerful display of the northern lights at any moment. Some hotels offer an 'aurora wake-up call'.



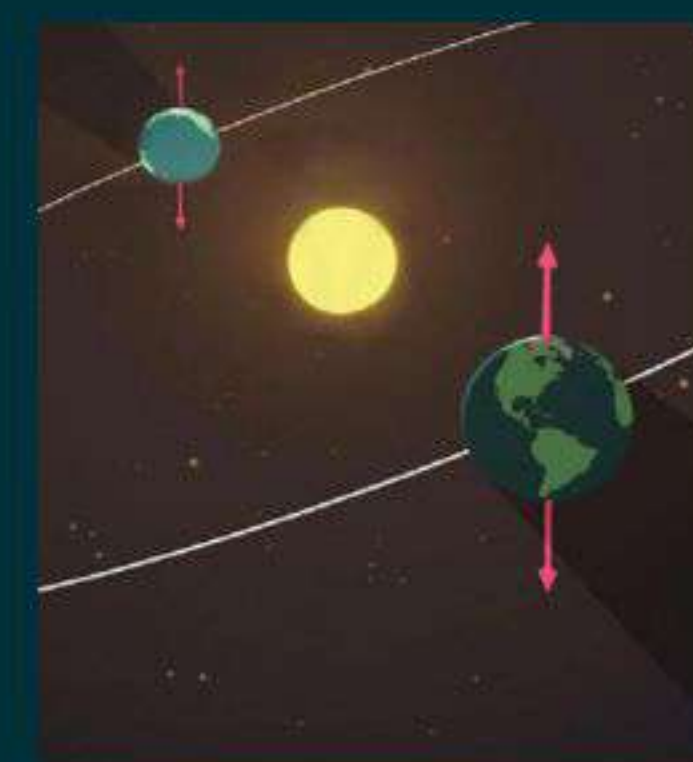
FIND A CLEAR SKY



7 There are two reasons why many people who journey to the Arctic Circle don't see a display. One is laziness; if you want a good night's sleep when in the Arctic Circle, don't expect to see them. The other reason is cloud, which is common in arctic winters, so if you have a car be prepared to search for gaps between clouds.

AIM FOR EQUINOX

8 The equinoxes in September and March are the two moments in our orbit around the Sun when the Earth's axis is tilted side-on to the solar wind. At these times the solar wind's magnetic field is facing southward relative to the Earth, so everything is lined up nicely. Consequently, displays of the northern lights can be stronger around the equinoxes.



STAY IN A REMOTE LODGE



9 A big reason for not seeing the northern lights is not spending enough time in remote areas of the Arctic Circle region. That makes spending a week in a rural lodge a great way of maximising your chances. If you choose Iceland or Scandinavia, you'll probably get a hot tub to watch them from, too.

BOOK A NORTHERN LIGHTS TOUR

10 The need to keep mobile to search for clear and dark skies - and worries about being able to take decent photographs properly - make an organised northern lights tour useful to many people. Usually a van will pick you up from your hotel and drive you around until the early hours of the following morning. It's worth the effort.



Take a cruise



11 An easy and relaxed way to view the northern lights is from the deck of a cruise ship. There are many that make the trip from the UK to the northern Norwegian coastline from Bergen up to Kirkenes, with the coast of Alaska another popular choice. Most such cruises include lectures.

Northern lights



TAKE A FLIGHT

12 A shortcut to seeing the northern lights can be to take a dedicated aurora flight, an evening excursion to the skies above the Arctic Circle to see them from above the clouds. They usually include a lecture, though be aware that seeing the northern lights through a small window can lack impact.

USE THE RIGHT CAMERA

13 To take a good photograph of the northern lights requires taking a long exposure of as little as five seconds to up to 25 seconds, depending on how bright the display is. DSLR or mirrorless cameras with manual modes are recommended, though some compact cameras and even some newer, updated smartphones now have long-exposure options.



CHOOSING A LENS AND TRIPOD

14 Although you don't need to upgrade your camera lens before you go, know that most epic images of the northern lights are from cameras fitted with a particularly wide-angle lens, such as a 14mm. Choose a tripod that feels sturdy and reaches head height, which does make things easier.

KNOW YOUR CAMERA

15 How well do you know your camera? One of the biggest challenges with taking pictures of the northern lights is that you frequently have to fiddle with the shutter speed and ISO. Can you do that quickly in the dark? Practise at home with the lights off before you get anywhere near the Arctic Circle to be sure.



TAKING PHOTOGRAPHS

16 Although it's a manual process, capturing the northern lights is simple. Set your camera to record in raw and JPEG, manually focus on infinity - the ∞ mark on your lens - choose ISO 800 and open the shutter for between five (for a bright display) and 25 seconds (for a faint display). Now experiment - and use Photoshop to bring out more detail when you get home.

EXPLAINING THE PHENOMENON

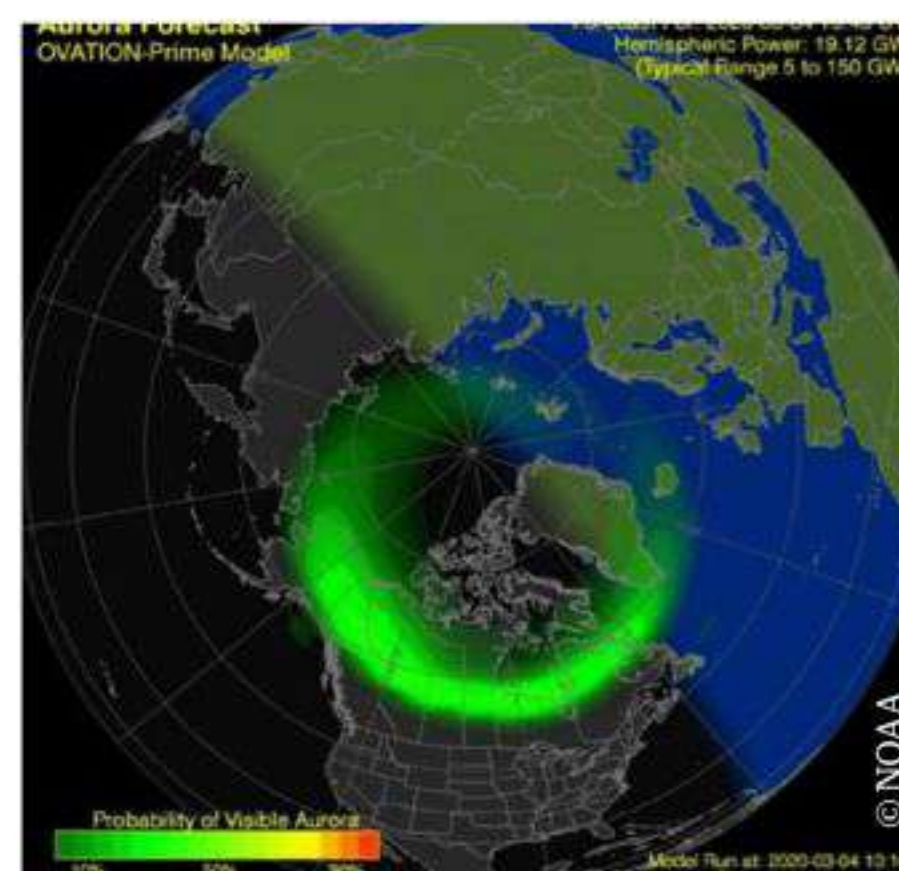
17 If you go on a northern lights hunt with anyone else, they're bound to ask you about the causes of the phenomenon. Can you explain it? The northern lights are caused by the solar wind - charged particles from the Sun - getting accelerated down the field lines of the Earth's magnetic field and exciting atoms of oxygen, which release a photon of light.

Other elements in the atmosphere can also create pinks and reds.



UNDERSTANDING THE AURORAL OVAL

18 On predictions you'll often see a map of the planet with an 'auroral oval' around Earth's geomagnetic North Pole. This oval is the boundary between the highly stretched magnetic



field lines of the polar cap and the more normal field lines at lower latitudes. When there's a 'solar storm', the oval shifts south.

ARC, BANDS AND PILLARS

19 The most common structure you will see during any display of the northern lights is a slow-moving diffuse arc, which is typical of low activity. Rippling ribbon-like bands are indicative of a stronger display and a truly impressive sight to behold, with 'dancing' beam-like pillars a sign that a incredibly intense display has arrived.



THE CAPTIVATING CORONA

20 What kind of northern lights display you see depends on where it's occurring in relation to you. If there is a strong display of pillars, you're in luck, and if you are beneath those pillars, then you will see something incredible. Call the auroral corona, you'll see a pulsating, almost mouth-like display that will get you hooked on the northern lights forever.

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STARGAZER

ESSENTIAL GUIDES AND ADVICE FOR AMATEUR ASTRONOMERS

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AL OBSERVATORY
GREENWICH

STARGAZING
BEGINNERS GUIDE TO ASTRONOMY

and Tom Kerss

**26
MAR**



Dwarf planet Makemake reaches opposition in Coma Berenices at +17.2



© NASA, ESA

**27
MAR**



Venus reaches half phase in the evening sky, dazzling at magnitude -4.4

**2
APR**



The Sombrero Galaxy (M104) is well placed for observation in Virgo, glowing at +8.0

**3
APR**



Asteroid 3 Juno reaches opposition in the constellation Virgo, glowing at +9.7

**5
APR**



Spiral galaxy Messier 94 is well placed for observation in Canes Venatici at +8.2



© NASA, ESA

**15
APR**



The Whirlpool Galaxy (Messier 51) is well placed for observation in Canes Venatici

**15
APR**



Conjunction between the Moon and Saturn in Capricornus

**16
APR**



Asteroid Haumea reaches opposition in Boötes, glowing at magnitude +17.3



Source: Wiki Commons © Renephoto

**22
APR**



The Lyrids reach their peak of 18 meteors per hour

Jargon buster

Conjunction

A conjunction is an alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Right Ascension (RA)

Right Ascension is to the sky what longitude is to the surface of the Earth, corresponding to east and west directions. It is measured in hours, minutes and seconds since, as the Earth rotates on its axis, we see different parts of the sky throughout the night.

Declination (Dec)

This tells you how high an object will rise in the sky. Like Earth's latitude, Dec measures north and south. It's measured in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and there are 60 arcminutes in a degree.

Magnitude

An object's magnitude tells you how bright it appears from Earth. In astronomy, magnitudes are represented on a numbered scale. The lower the number, the brighter the object. So, a magnitude of -1 is brighter than an object with a magnitude of +2.

Opposition

When a celestial body is in line with the Earth and Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

Greatest elongation

When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongations and as morning stars during western elongations.

**27
MAR**



Venus reaches its highest point in the evening sky, dazzling at magnitude -4.4

**31
MAR**



Conjunction between Saturn and Mars in Capricornus

**31
MAR**



Saturn and Mars make a close approach, passing within 0°54' of each other in Capricornus

**9
APR**



Conjunction between Jupiter and Pluto in Sagittarius

**15
APR**



Conjunction between the Moon and Jupiter in Sagittarius

**15
APR**



The Moon, Jupiter and Pluto make a close approach, within 1°59' of each other in Sagittarius

**15
APR**



The Moon and Saturn pass within 2°26' of each other in Capricornus

**16
APR**



Conjunction between the Moon and Mars in Capricornus

**16
APR**



The Moon and Mars pass within 1°57' of each other in Capricornus

**23
APR**



The Pinwheel Galaxy (M101) is well placed for observation in Ursa Major at +7.9

**26
APR**



Conjunction between the Moon and Venus in Taurus

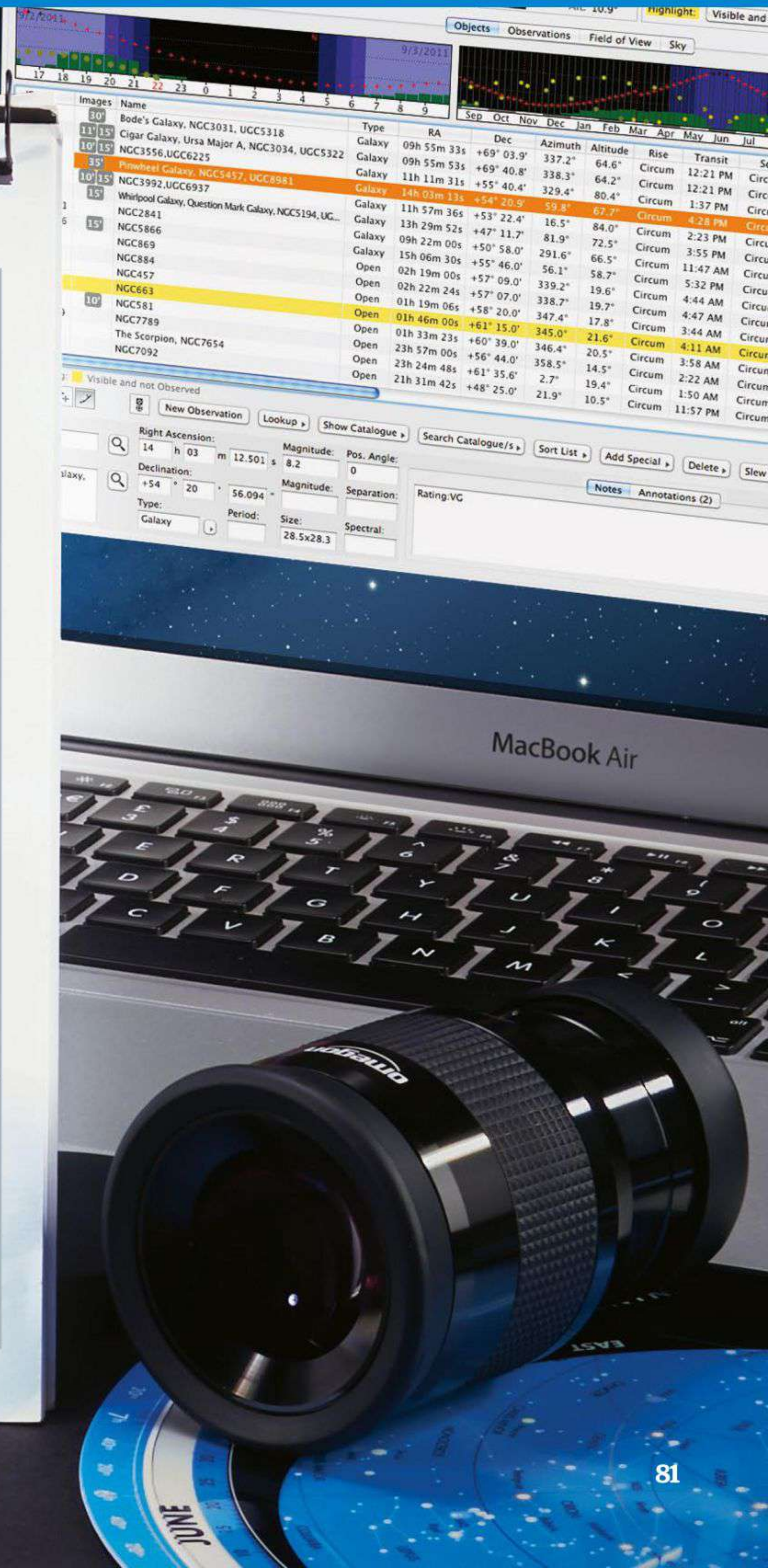
Naked eye

Binoculars

Small telescope

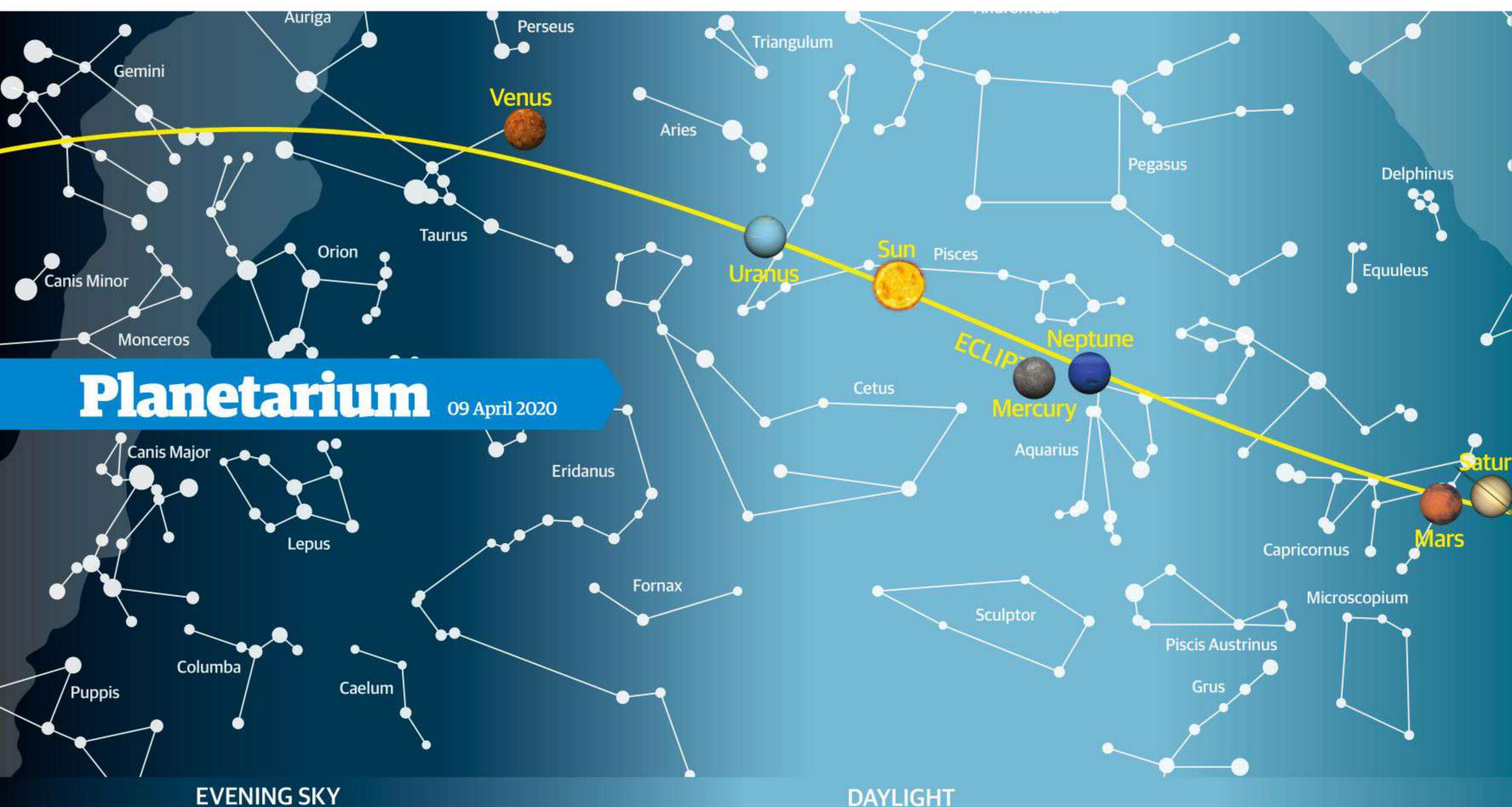
Medium telescope

Large telescope





STARGAZER



Moon calendar

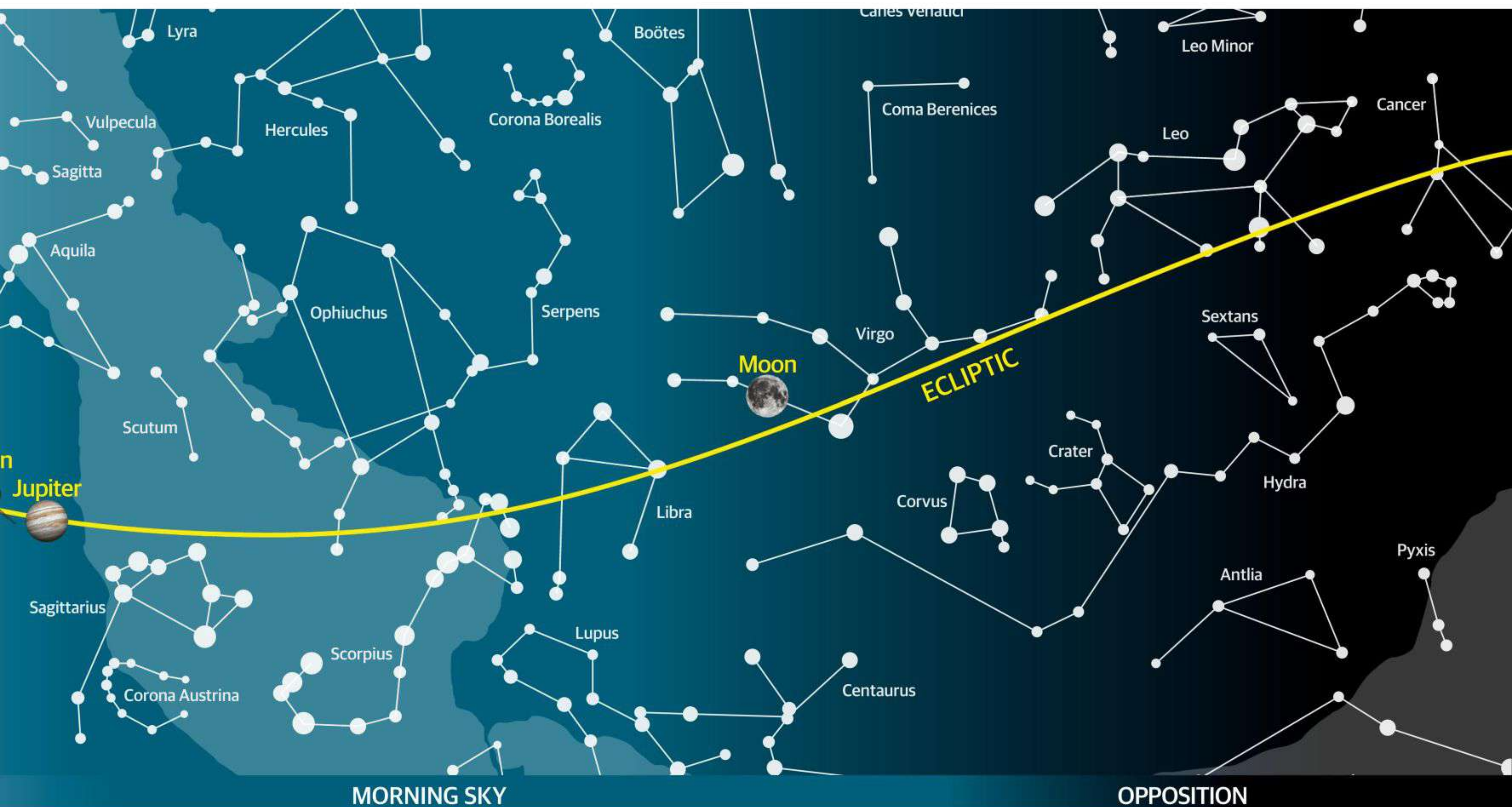
* The Moon does not pass the meridian on 6 April

26 MAR 4.4% ☀ 06:59 ☾ 20:35	27 MAR 9.1% ☀ 07:16 ☾ 21:43	28 MAR 15.6% ☀ 07:36 ☾ 22:51	29 MAR 23.5% ☀ 09:00 ☾ ---
30 MAR 32.7% ☀ 00:59 ☀ 09:30	31 MAR 42.9% ☀ 02:06 ☀ 10:09	1 APR FQ 53.7% ☀ 03:07 ☀ 10:58	2 APR 64.8% ☀ 04:00 ☀ 12:00
3 APR 75.4% ☀ 04:44 ☀ 13:13	4 APR 85.0% ☀ 05:19 ☀ 14:34	5 APR 92.7% ☀ 05:48 ☀ 16:00	
6 APR ---%* ☀ 06:13 ☀ 17:27	7 APR 97.8% ☀ 06:35 ☀ 18:55	8 APR FM 99.8% ☀ 06:56 ☀ 20:23	9 APR 98.5% ☀ 07:19 ☀ 21:51
10 APR 94.1% ☀ 07:44 ☀ 23:16	11 APR 87.1% ☀ 08:15 ☀ ---	12 APR 78.2% ☀ 00:36 ☀ 08:52	
13 APR 68.1% ☀ --- ☀ ---	14 APR TQ 57.5% ☀ 10:48 ☀ ---	15 APR 46.9% ☀ 11:44 ☀ ---	16 APR 36.8% ☀ 12:47 ☀ ---
17 APR 27.4% ☀ 05:05 ☀ 13:54	18 APR 19.1% ☀ 05:31 ☀ 15:02	19 APR 12.1% ☀ 05:53 ☀ 16:09	
20 APR 6.5% ☀ 06:11 ☀ 17:16	21 APR 2.6% ☀ 06:27 ☀ 18:22	22 APR 0.5% ☀ 06:43 ☀ 19:29	23 APR NM 0.3% ☀ 06:59 ☀ 20:35

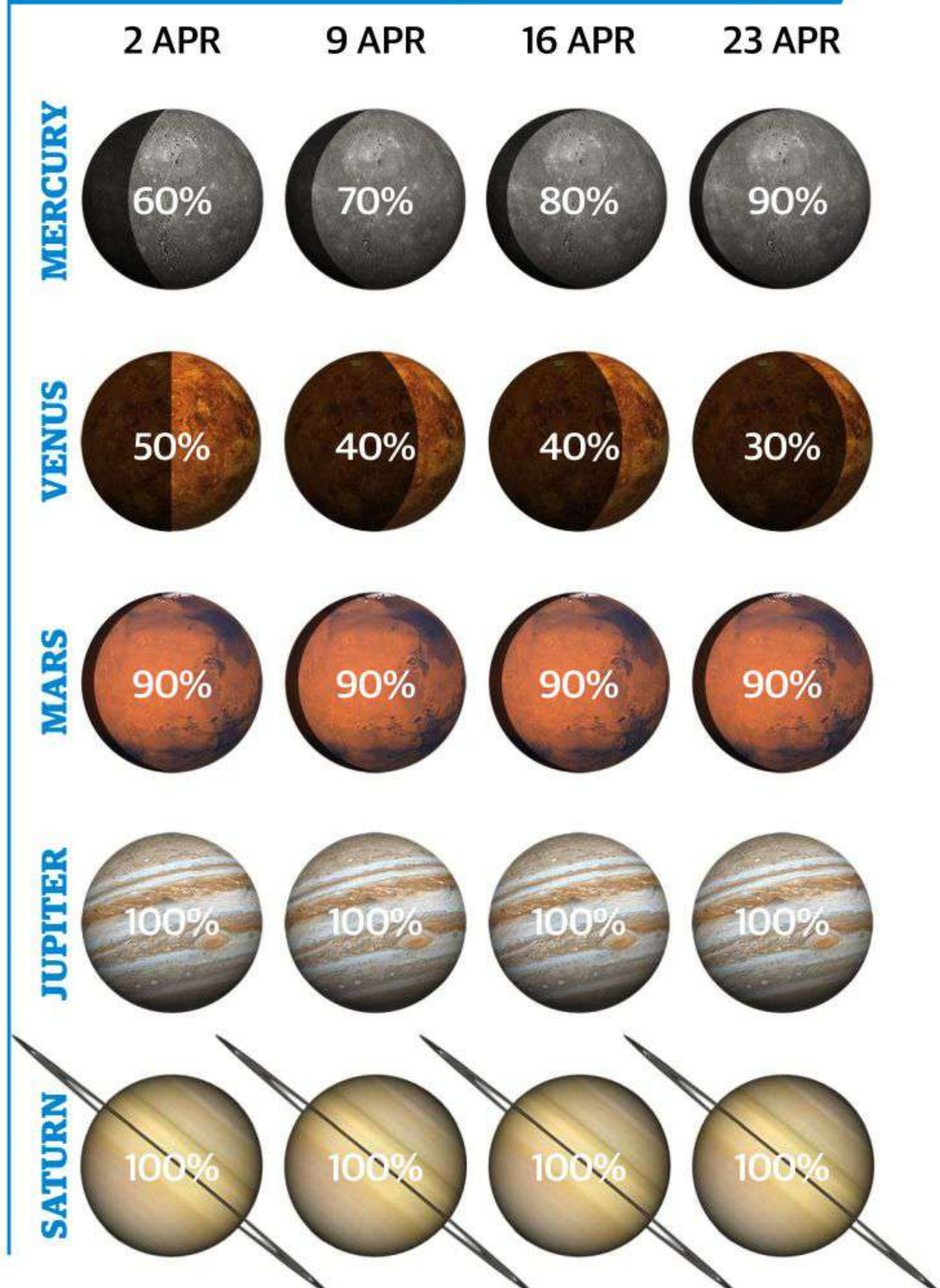
% Illumination
☀ Moonrise time
☾ Moonset time

FM Full Moon
NM New Moon
FQ First quarter
TQ Third quarter

All figures are given for 00h at midnight (local times for London, UK)



Illumination percentage



Planet positions

All rise and set times are given in GMT/BST

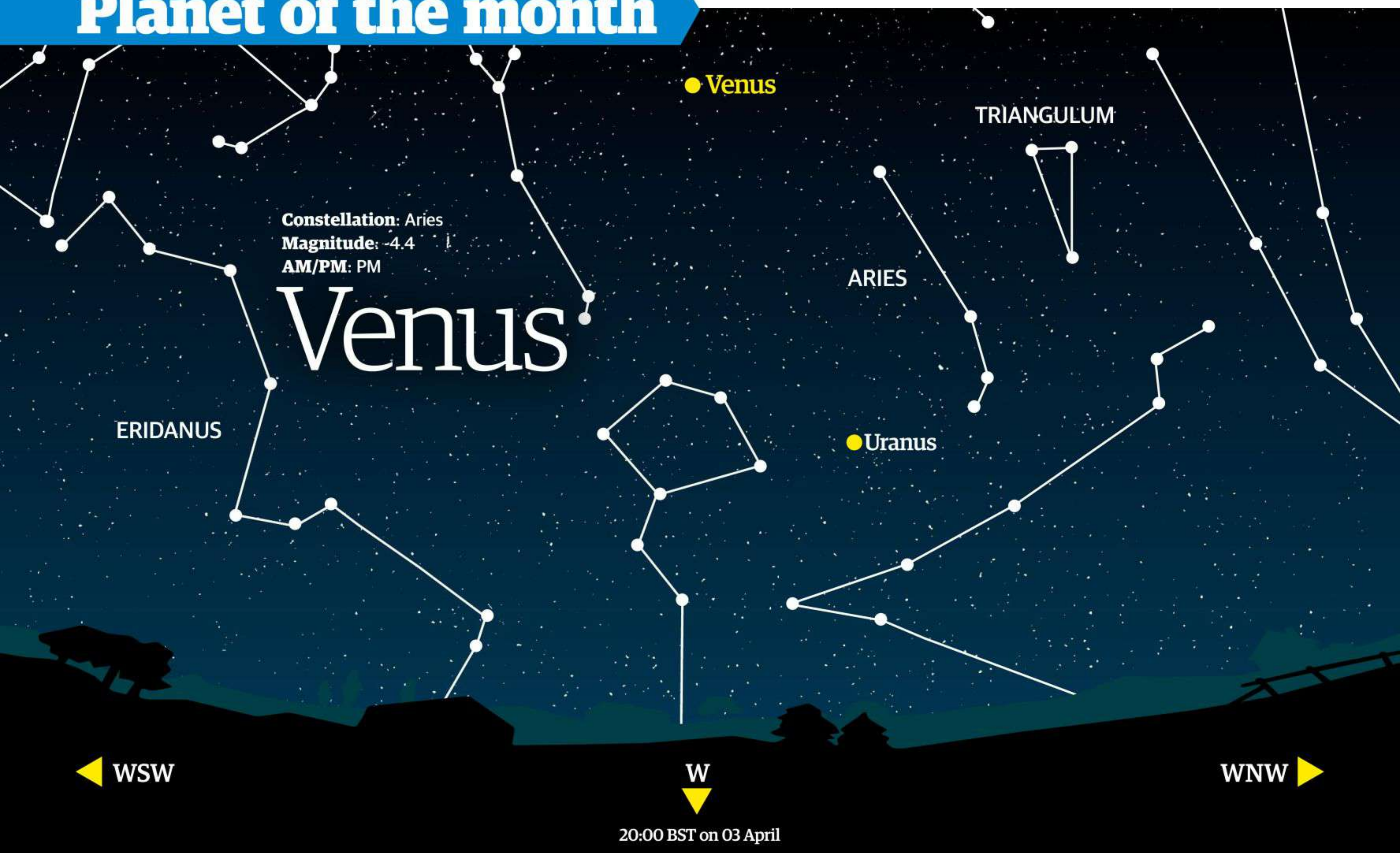
	Date	RA	Dec	Constellation	Mag	Rise	Set
MERCURY	26 MAR	22h 40m 25s	-10° 02' 09"	Aquarius	0.1	05:12	15:37
	2 APRIL	23h 13m 07s	-07° 26' 35"	Aquarius	-0.0	06:03	16:55
	9 APRIL	23h 50m 27s	-03° 46' 12"	Aquarius	-0.2	05:54	17:24
	16 APRIL	00h 31m 48s	+00° 49' 54"	Cetus	-0.4	05:45	18:01
	23 APRIL	01h 17m 38s	+06° 11' 50"	Cetus	-0.9	05:36	18:46
VENUS	26 MAR	03h 12m 50s	+21° 10' 13"	Aries	-4.4	06:55	22:57
	2 APRIL	03h 40m 05s	+23° 18' 57"	Taurus	-4.4	07:40	00:16
	9 APRIL	04h 06m 04s	+25° 03' 17"	Taurus	-4.4	07:25	00:27
	16 APRIL	04h 30m 01s	+26° 22' 10"	Taurus	-4.5	07:11	00:34
	23 APRIL	04h 50m 59s	+27° 15' 27"	Taurus	-4.5	06:57	00:35
MARS	26 MAR	19h 54m 15s	-21° 42' 47"	Sagittarius	0.9	03:34	11:43
	2 APRIL	20h 14m 48s	-20° 50' 51"	Capricornus	0.9	04:22	12:42
	9 APRIL	20h 35m 07s	-19° 50' 35"	Capricornus	0.9	04:08	12:41
	16 APRIL	20h 55m 10s	-18° 42' 39"	Capricornus	0.9	03:53	12:40
	23 APRIL	21h 14m 56s	-17° 27' 48"	Capricornus	0.5	03:38	12:40
JUPITER	26 MAR	19h 40m 46s	-21° 28' 17"	Sagittarius	-2.1	03:19	11:31
	2 APRIL	19h 44m 37s	-21° 19' 42"	Sagittarius	-2.2	03:55	12:08
	9 APRIL	19h 47m 59s	-21° 12' 06"	Sagittarius	-2.2	03:30	11:45
	16 APRIL	19h 50m 48s	-21° 05' 41"	Sagittarius	-2.3	03:04	11:21
	23 APRIL	19h 53m 04s	-21° 00' 40"	Sagittarius	-2.3	02:38	10:56
SATURN	26 MAR	20h 08m 47s	-20° 11' 56"	Capricornus	0.7	03:39	12:07
	2 APRIL	20h 10m 42s	-20° 06' 39"	Capricornus	0.7	04:13	12:42
	9 APRIL	20h 12m 19s	-20° 02' 10"	Capricornus	0.6	03:46	12:17
	16 APRIL	20h 13m 39s	-19° 58' 35"	Capricornus	0.6	03:20	11:51
	23 APRIL	20h 14m 40s	-19° 56' 18"	Capricornus	0.6	02:57	11:28



This month's planets

Although Venus rules the evening, Saturn, Jupiter and Mars continue their planetary parade before dawn

Planet of the month



Venus is our Planet of the Month this month not just because it will be a beautiful 'evening star' in the sky, and not because it will be dazzlingly bright, but because there will be so much happening around it. As soon as the Sun sets at the end of March you should start looking for Venus in the west, and it won't take you too long to find it – it's so bright this month. In fact it's about as bright as it ever gets. As long as you have a clear view to the west without any tall trees or buildings in the way, it will be clearly visible to your naked eye as a metallic 'spark' in the twilight, even from the middle of a light-polluted town or city, but if you are lucky enough to live somewhere with a dark sky and less light pollution it will be a simply stunning sight.

At the end of March Venus is joined in the sky by the waxing Moon. The two will be some 12 degrees apart in the twilight on 27 March, when the Moon will be shining almost directly below Venus. The following evening, when the Moon will be to the lower left of Venus, they'll be around half that distance apart. By the 29th the Moon will have moved up to Venus' upper left and will be around 14 degrees from it. On all of these evenings the pair will look lovely together. If you have a pair of binoculars, use them on the pair during this period. They really will look beautiful together.

However, that close encounter with the Moon is really just a warm-up act for Venus' early April rendezvous with one of the most famous star clusters in the sky. Between 1 and 5 April the

planet will appear to drift towards and then pass through the beautiful Pleiades star cluster in Taurus. Cross your fingers for clear skies on the evening of 3 April because then you'll see Venus shining almost slap bang in the middle of the star cluster, outshining all of the cluster's stars twinkling around it. This is a close encounter you really must look at through binoculars or a small telescope to see it at its best.

Once Venus has moved away from the Pleiades it will remain a striking naked-eye 'evening star' in the west after dark, heading up towards the southern end of the constellation of Auriga. On 22 April the planet will be shining to the upper left of the Pleiades and the upper right of the brightest star in Taurus, orange-hued Aldebaran.

Mercury 06:30 BST on 07 April



Constellation: Aquarius

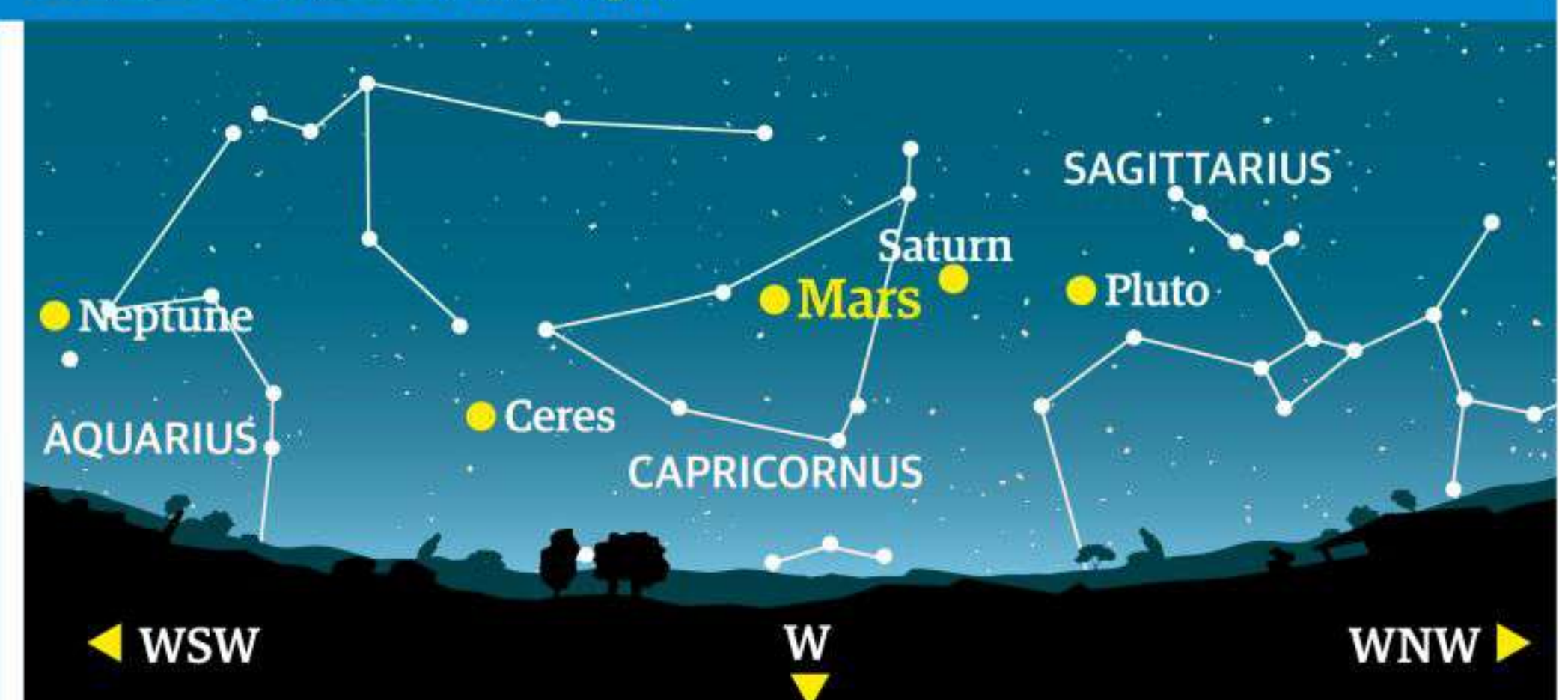
Magnitude: +0.2

AM/PM: AM

Don't get too excited by that magnitude of +0.2 – this will be a very poor month for Mercury-

watchers. As cold March edges towards milder April the closest planet to the Sun will technically be a morning object, but it is already closing in on the Sun, and by April it will be too close to it to be seen.

Mars 06:30 BST on 16 April



Constellation: Sagittarius

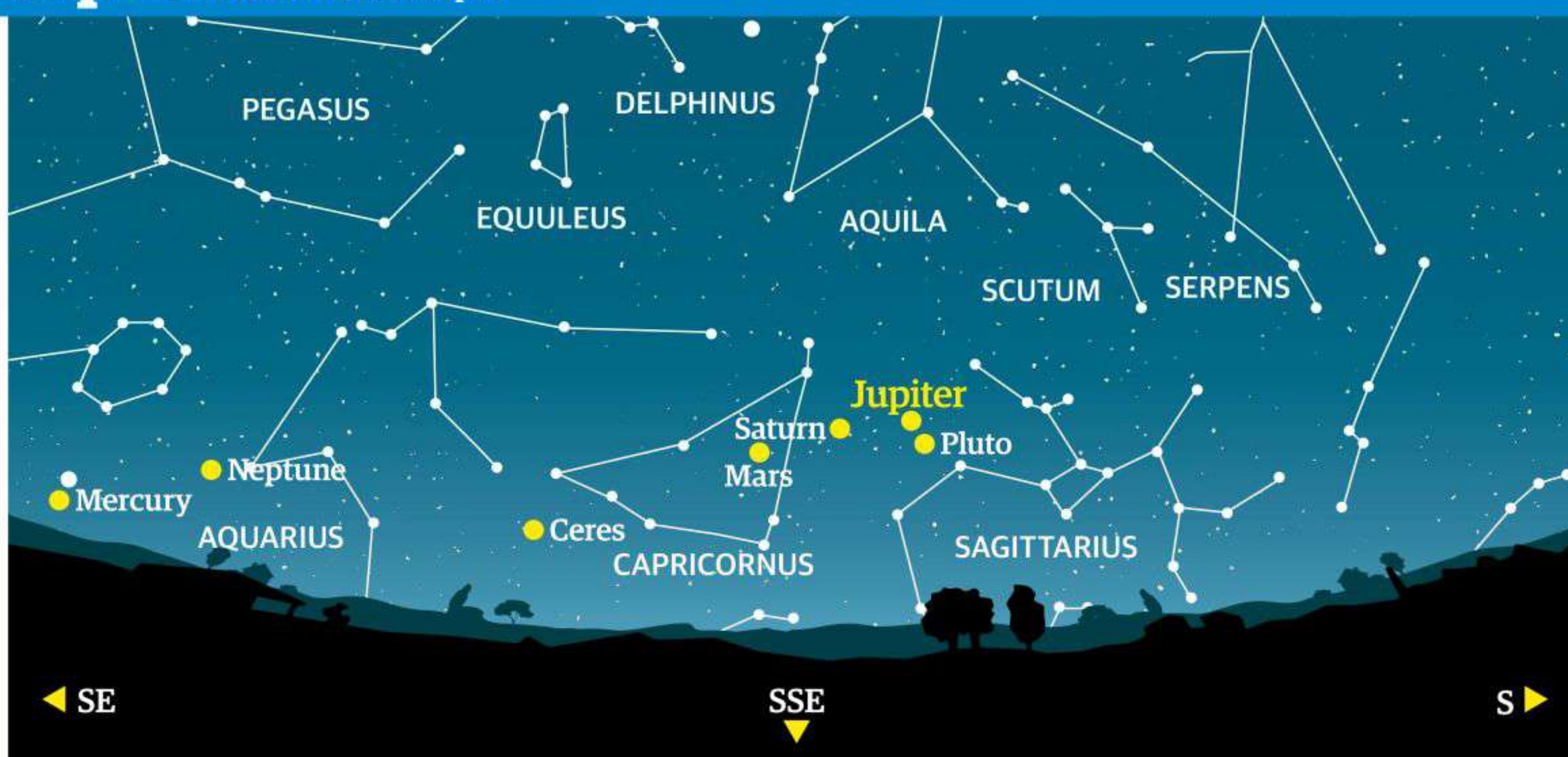
Magnitude: +0.9

AM/PM: AM

At the start of our observing period Mars will be halfway between brighter Saturn to its left and much

brighter Jupiter to its right, but as March moves into April Mars will drift towards and then past Saturn. Look out for the two less than a degree apart on the mornings of 31 March and 1 April.

Jupiter 06:30 BST on 11 April



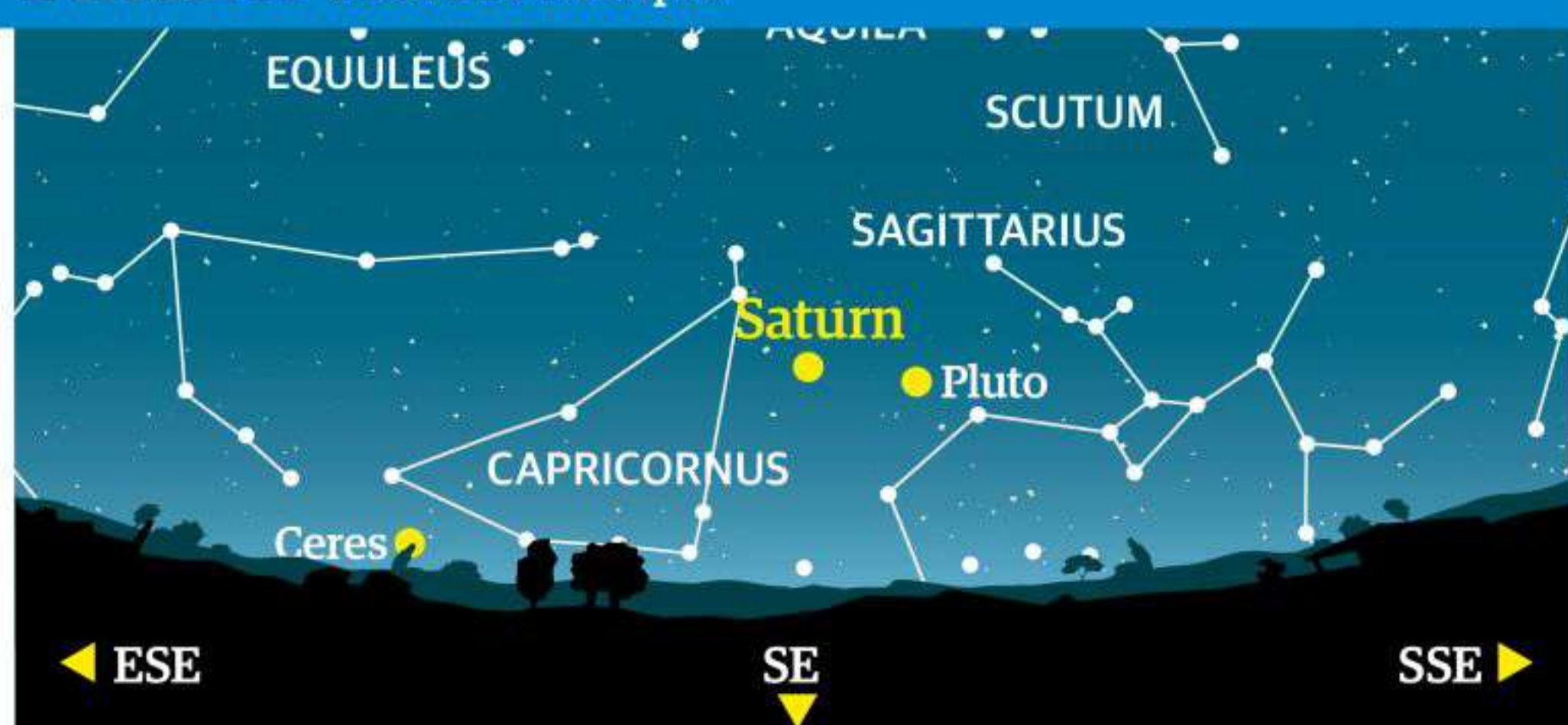
Constellation: Sagittarius

Magnitude: -2.1

AM/PM: AM

The largest world in the Solar System is a very bright 'morning star' clearly visible to the naked eye, low in the southeast before sunrise, with much fainter Mars to its lower left and slightly fainter Saturn even further in the same direction. At magnitude -2.1 it is a lovely sight on its own, but it will look even lovelier on the mornings of 14 to 16 April, when a waning Moon will pass gracefully beneath it. You'll need a telescope to see Jupiter's cloud bands, but a pair of binoculars will show you the planet's four largest moons as tiny stars hugging close to it.

Saturn 06:30 BST on 1 April



Constellation: Capricornus

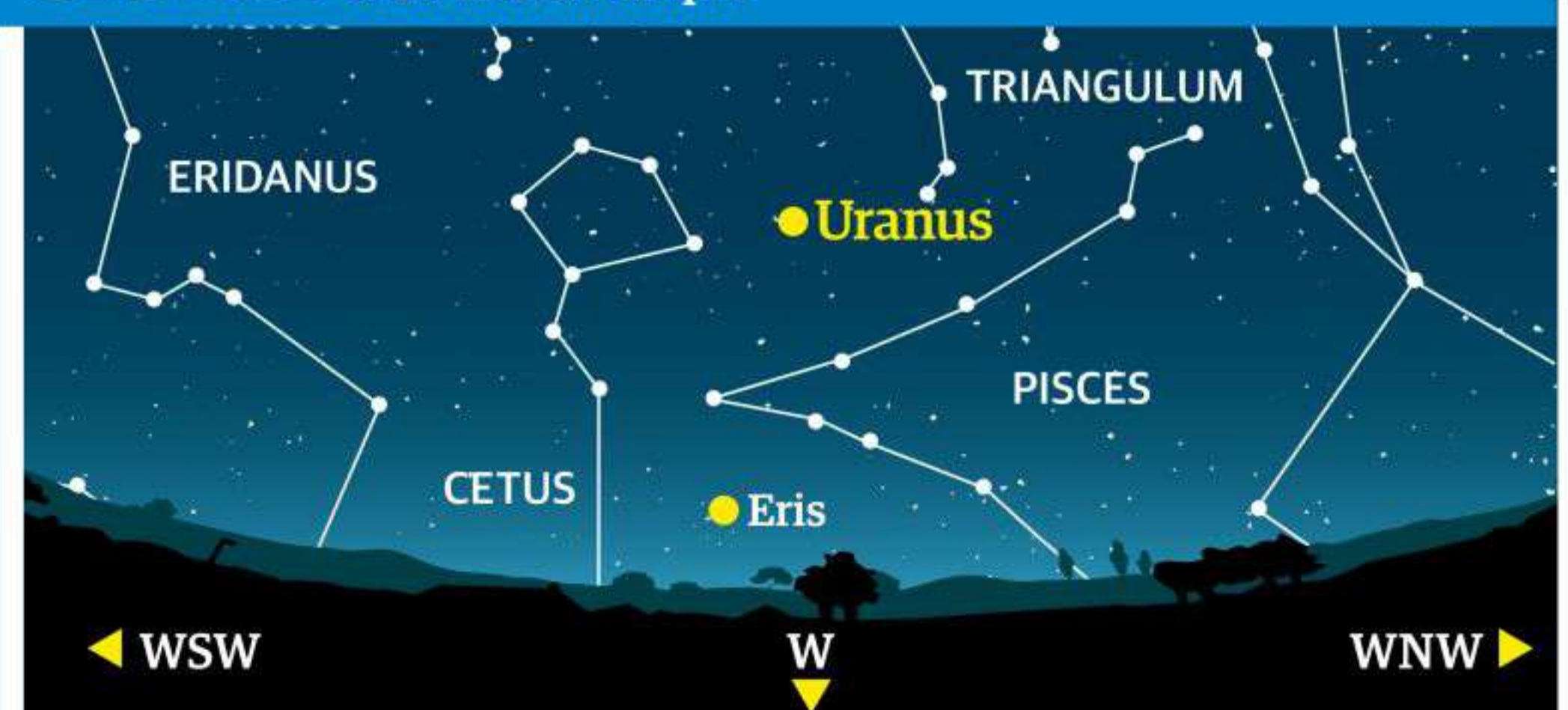
Magnitude: +0.7

AM/PM: AM

Along with fainter Mars and much brighter Jupiter, Saturn is a 'morning star', perfectly visible to the naked

eye in the east before sunrise. A telescope will show the planet's famous rings, but even a pair of binoculars will show you Saturn's largest moon, Mercury-sized Titan, as a 'star' close to it.

Uranus 19:30 BST on 01 April



Constellation: Aries

Magnitude: +5.9

AM/PM: PM

This month you'll need binoculars to see Uranus in the twilight, low down in the west after sunset,

to the lower right of far brighter Venus. The two planets begin our observing period some 18 degrees apart and will pull a little further apart each evening, but after 1 April Uranus will no longer be visible.



Top tip!

Mare Crisium is at its most obvious on or around full Moon, when it is clearly visible to the naked eye near the top right of the rugged lunar disc.

Moon tour

Mare Crisium

As Venus blazes beside the Moon this month, look for one of our natural satellite's most famous seas

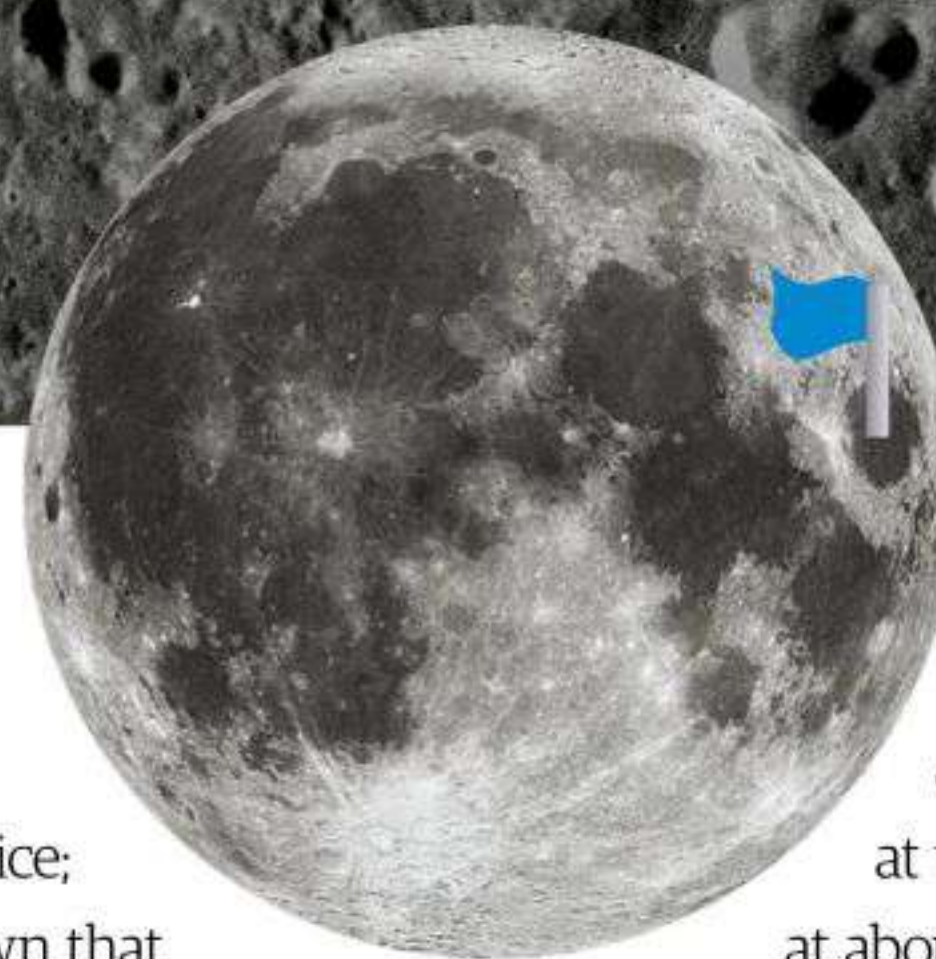
Weather permitting, at the end of March we will be treated to a lovely sight in the evening sky: Venus, the beautiful 'evening star', will be shining lantern-bright in the west after sunset, close to a slender crescent Moon. The two worlds will be so close together in the evening twilight for three consecutive nights that they will draw the eye away from everything else and have amateur astronomers reaching for their binoculars and non-astronomers attempting to photograph them with their phone cameras. Not even light pollution will stop this pairing from being a memorable sight, but if your sky is very clear and dark you will also be able to see the dark part of the Moon's face glowing with a subtle lavender hue, a light which astronomers affectionately call 'Earthshine', as it is caused by sunlight reflecting off the Earth's clouds and oceans rather than direct light from the Sun.

If you have a pair of binoculars the end of March will also be a great time to see one of the most famous - and most easy to find - features on the Moon: Mare Crisium, the Sea of Crises. As you look at the crescent phase on the last few evenings of March you'll see a dark circular patch on it, towards the top.

That's Mare Crisium, a vast plain of ancient, dark lava which covers the floor of the Crisium basin. In fact, the term 'vast' doesn't do it justice; measurements from orbit have shown that Mare Crisium is more than 550 kilometres (342 miles) wide, and covers an area of roughly 176,000 square kilometres (67,954 square miles).

Astronomers believe this monstrous feature was formed between 3.9 and 4.5 billion years ago, when a large asteroid slammed into the Moon so hard it didn't just blast out an enormous hole but flooded that hole with lava, spreading a vast pool of melted rock and debris across its floor which eventually cooled and set, leaving behind the dark, round 'sea' we see today. Today that lunar sea is so obvious to the naked eye and through the eyepieces of binoculars and telescopes that it is very hard to miss it. In fact, even if you know absolutely nothing about the Moon and its surface features, you'll have seen Mare Crisium already without even trying.

While the end of March will be the perfect time to find Mare Crisium, as it dominates the slender

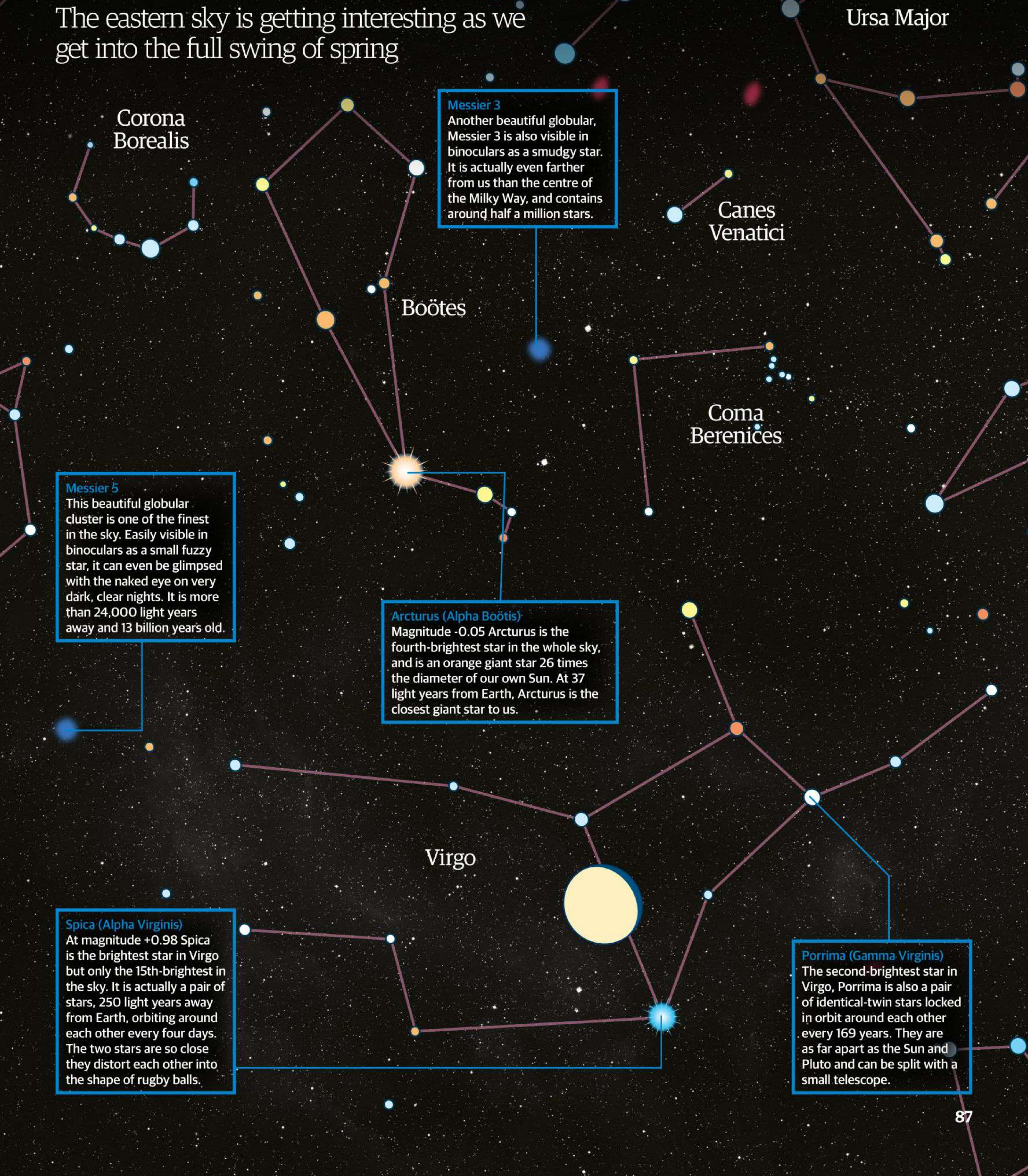


crescent which will be seen shining close to Venus, it's easy to find at any time as a small, dark oval shape at the top right of the lunar disc, up at about the one o'clock position. It's very obvious through a small telescope, or just the smallest pair of binoculars, but it's easily visible to the naked eye too.

At the end of March Mare Crisium will stand out starkly on the lunar crescent, a dark oval area near the top of the horn. This will be the best time to see it through a telescope because the Sun's low slanting rays will be casting stark shadows behind the small bumps, craterlets and jagged ridges scattered across its floor. As the days pass and that crescent grows to become a first-quarter Moon on 1 April and then a gibbous Moon, Mare Crisium remains clearly visible. It is still clearly visible when the Moon becomes full on 7 April, but by the 9th the terminator - the line between night and day - will lie across its eastern edge. By the following evening it will have been plunged into darkness. It will remain out of view for the rest of our observing period.

Naked eye & binocular targets

The eastern sky is getting interesting as we get into the full swing of spring



Corona Borealis

Messier 3
Another beautiful globular, Messier 3 is also visible in binoculars as a smudgy star. It is actually even farther from us than the centre of the Milky Way, and contains around half a million stars.

Ursa Major

Canes Venatici

Boötes

Coma Berenices

Messier 5
This beautiful globular cluster is one of the finest in the sky. Easily visible in binoculars as a small fuzzy star, it can even be glimpsed with the naked eye on very dark, clear nights. It is more than 24,000 light years away and 13 billion years old.

Arcturus (Alpha Boötis)
Magnitude -0.05 Arcturus is the fourth-brightest star in the whole sky, and is an orange giant star 26 times the diameter of our own Sun. At 37 light years from Earth, Arcturus is the closest giant star to us.

Virgo

Spica (Alpha Virginis)
At magnitude +0.98 Spica is the brightest star in Virgo but only the 15th-brightest in the sky. It is actually a pair of stars, 250 light years away from Earth, orbiting around each other every four days. The two stars are so close they distort each other into the shape of rugby balls.

Porrina (Gamma Virginis)
The second-brightest star in Virgo, Porrina is also a pair of identical-twin stars locked in orbit around each other every 169 years. They are as far apart as the Sun and Pluto and can be split with a small telescope.



Pacman Nebula
(NGC 281)

Deep sky challenge

Cassiopeia's dark-sky royalty

How to track down some of the Queen's most sneakily concealed crown jewels

Many amateur astronomers think Cassiopeia is a rather barren constellation, and perhaps compared to its more glitzy neighbours it is. For example, nearby Perseus has the stunning and famous 'Double Cluster' of NGC 869 and NGC 884, Taurus has its show-stopping Pleiades cluster and of course Andromeda holds the stunning Andromeda Galaxy, Messier 31. But if you take the time to look a little more closely at Cassiopeia, the infamously vain queen of the sky, you'll find quite a few attractive deep-sky objects hidden within the folds of her royal robes.

First of all, Messier 103 positively demands you look at it through as big a telescope as possible. It might have been the last object Messier put in his catalogue, but it's far from the least attractive. Close to it, NGC 457 is also worth a look if you're lucky to find yourself at your scope's eyepiece on a beautiful dark night with no Moon or nearby light pollution.

Close to the star Gamma Cassiopeia you'll find not one but two swirly nebulae, beautiful subtle arcs of misty light. You'll need your best eyepiece and perfect seeing to glimpse the dark lanes and knots of dust within them.



Gamma Cassiopeiae
Nebula (IC 59 and 63)

Source: Wikipedia Commons © Kees Scherer

Source: Wikipedia Commons © Göran Nilsson, Hóla Observatory

1 NGC 663
8,000 light years away, this seventh-magnitude open cluster covers just 15' of sky and contains around 60 stars. Most are much fainter than seventh magnitude. It looks best in a high-power eyepiece.

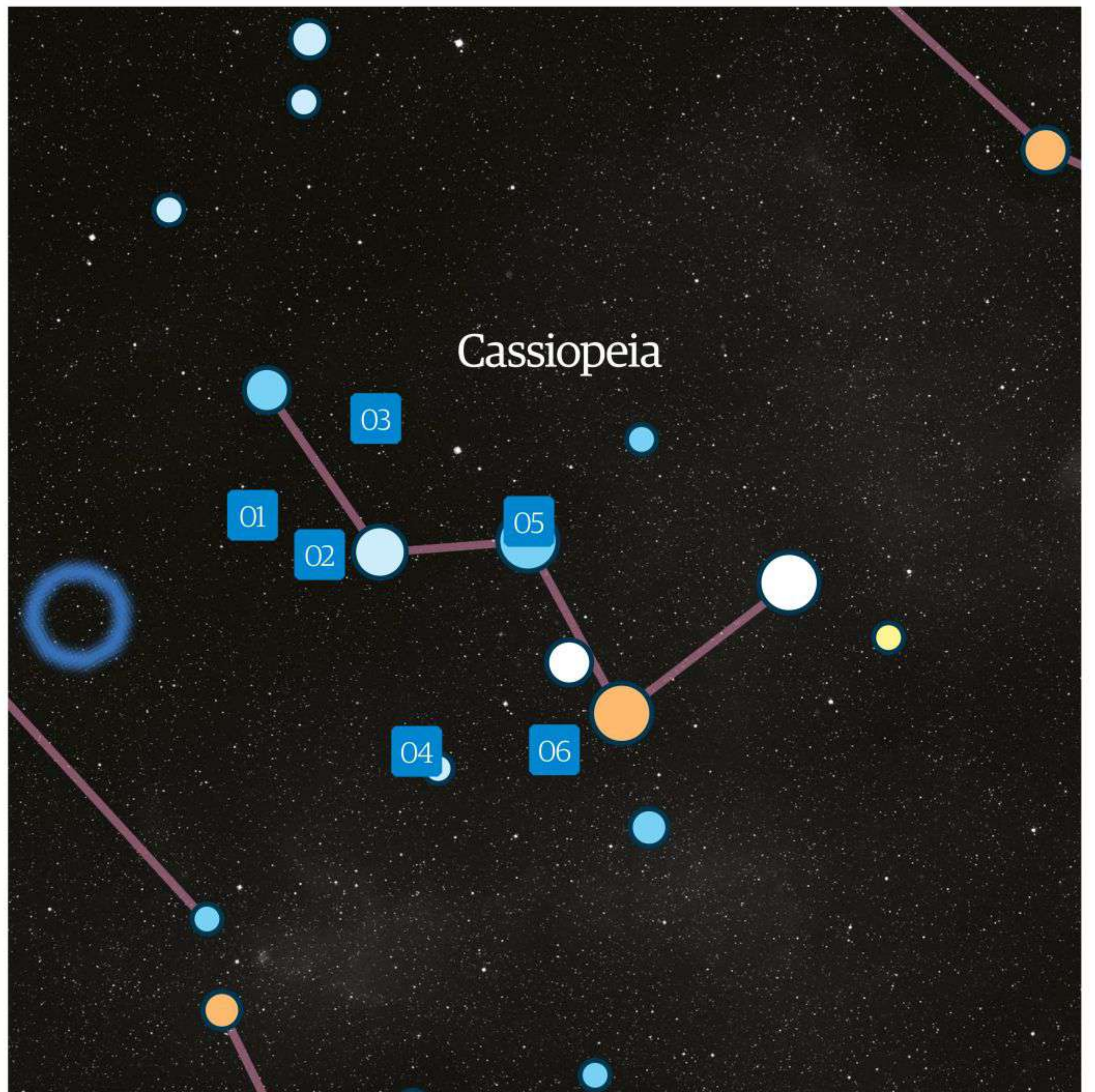
2 Messier 103
The final object catalogued by Messier, this cluster is a beautiful sight in a large telescope's low-power eyepiece. Its 40-plus stars make a distinct arrowhead shape with a vivid red star at its centre.

3 Caldwell 8 (NGC 559)
Also known as Caldwell 8, this magnitude-9.5 cluster is barely 4.4' across and is little more than a spray of faint stars. A challenge for large telescopes even on dark, Moon-free nights!

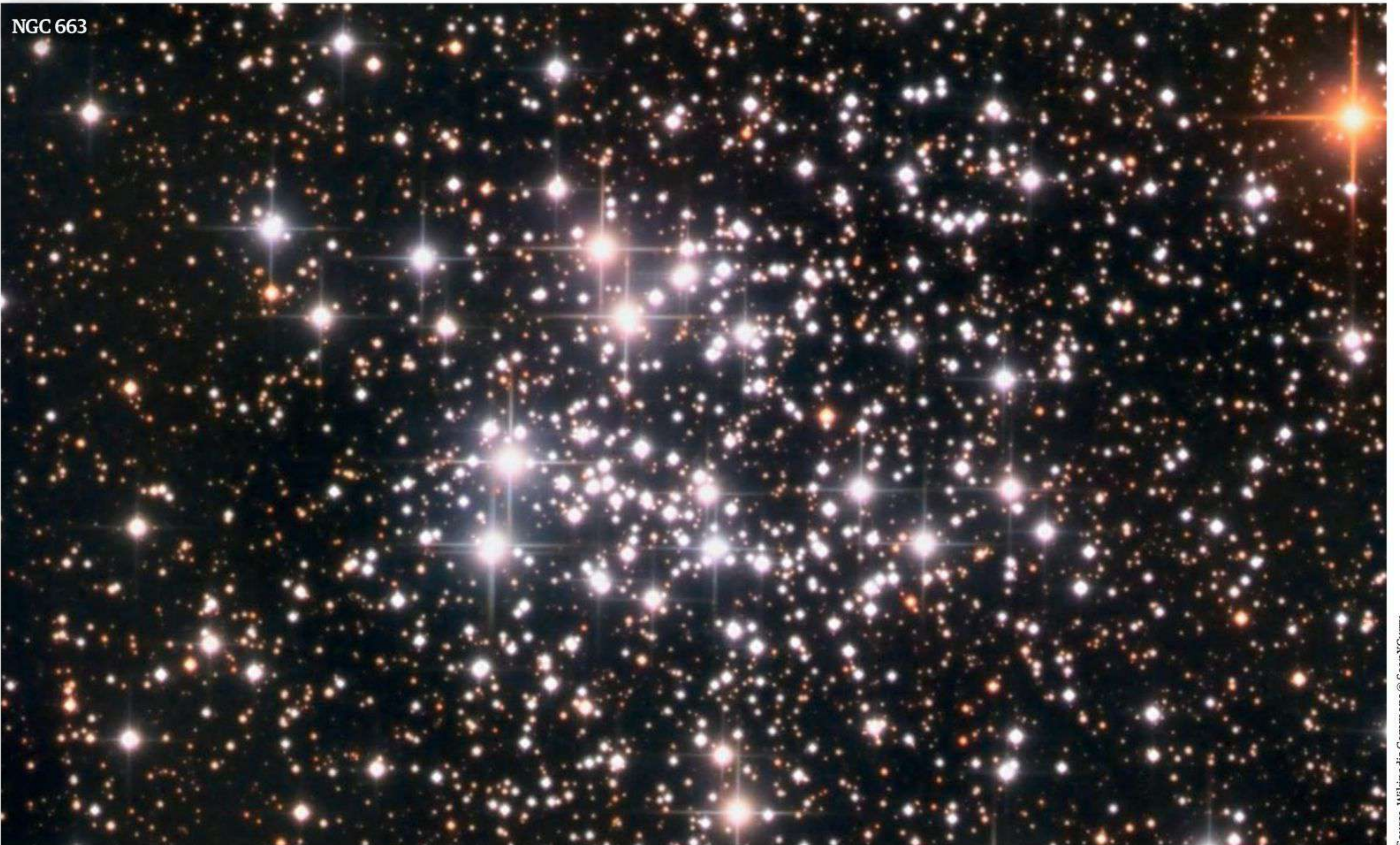
4 Owl Cluster (NGC 457)
Known as the 'Owl Cluster', this is one of the finest in the region. Triangle-shaped, large telescopes will resolve its compressed centre and the three lines of fainter stars leading away from it.

5 IC 59 and IC 63
This close pair of bright, arc-shaped nebulae look very pretty in a large telescope's high-power eyepiece. IC 63 is closest to Gamma Cassiopeia and is by far the brighter of the two.

6 Pacman Nebula (NGC 281)
Nicknamed the 'Pacman Nebula', this bright nebula has some fascinating interior detail - streamers, clumps and knots of material - only visible in larger telescopes.



NGC 663





The Northern Hemisphere

Spring lets us gaze out of the Milky Way's plane

Bright yellow-white star Capella of Auriga (the Charioteer) sits low in the northwestern sky this month, a striking sight at magnitude +0.08 alongside easy-to-locate Castor and Pollux of Gemini (the Twins). Ursa Major's 'Big Dipper' is the simplest asterism to find as soon as darkness falls, making it easy to use its pointer stars to find Polaris. Follow the pointers in the other direction and you will find bright-white star Regulus in Leo (the Lion); trace your finger along the bowl and you'll find yourself led to brilliant yellow-orange star Arcturus in the constellation of Boötes (the Herdsman). Nearby, just northeast of Arcturus, you'll be greeted by the beautiful and unmistakable semi-circle of the Northern Crown, Corona Borealis.

Using the sky chart

This chart is for use at 22:00 (BST) mid-month and is set for 52° latitude.

- 01 Hold the chart above your head with the bottom of the page in front of you.
- 02 Face south and notice that north on the chart is behind you.
- 03 The constellations on the chart should now match what you see in the sky.



Magnitudes

- Sirius (-1.4)
- -0.5 to 0.0
- 0.0 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- 1.5 to 2.0
- 2.0 to 2.5
- 2.5 to 3.0
- 3.0 to 3.5
- 3.5 to 4.0
- 4.0 to 4.5
- Fainter
- Variable star

Spectral types

- | | |
|-------|-----|
| • O-B | • G |
| • A | • K |
| • F | • M |

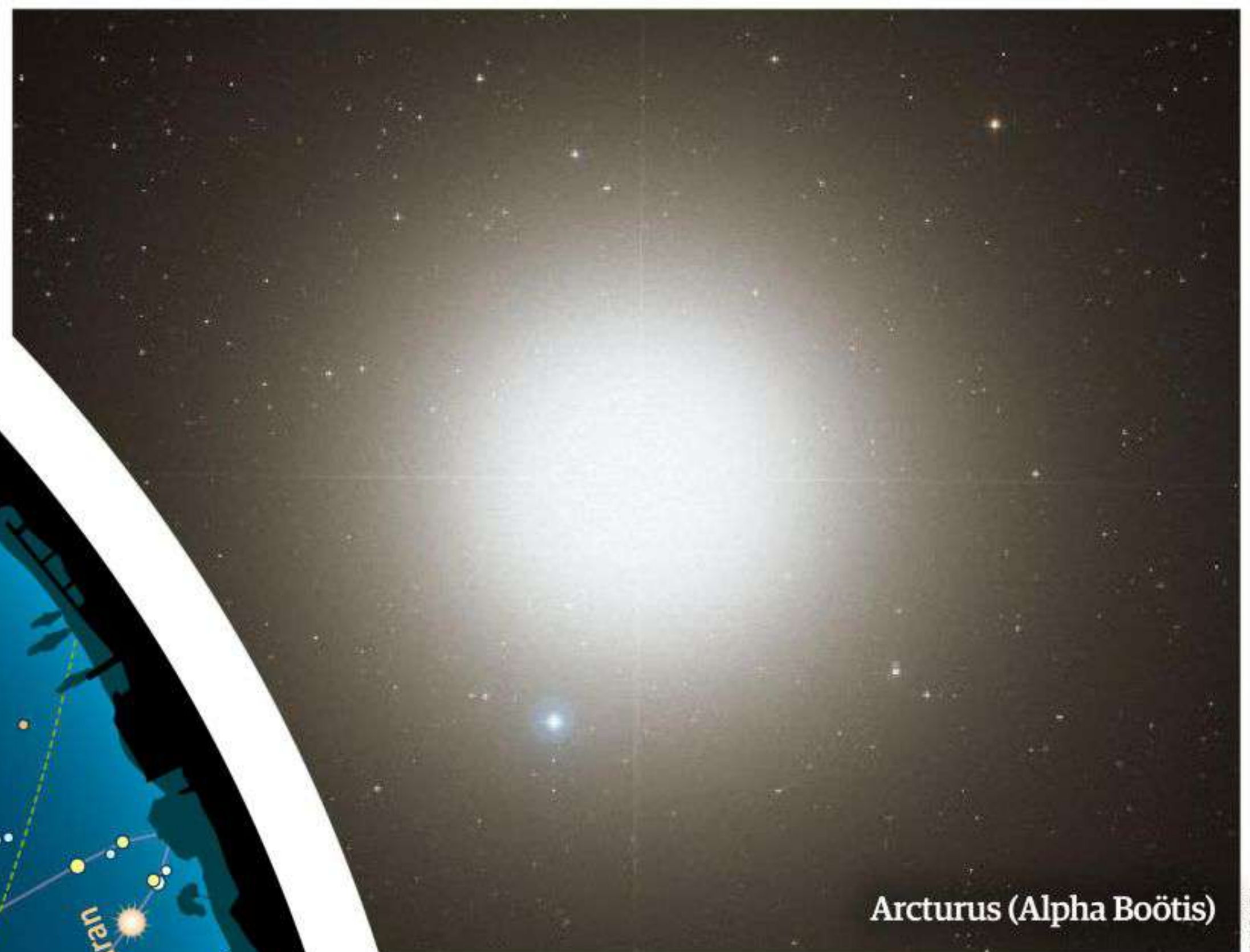
Deep-sky objects

- Open star clusters
- Globular star clusters
- Bright diffuse nebulae
- Planetary nebulae
- Galaxies



Observer's note:

The night sky as it appears on 17 April 2020 at approximately 22:00 (BST)



© NASA



Source: Wikipedia Commons © Martin Mark



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STARGAZER

Astrophotos of the month

Send your astrophotography images to space@spaceanswers.com for a chance to see them featured in **All About Space**

Bill Schlosser



Michigan, US
Telescope:
Meade LX850
14" Schmidt-
Cassegrain, Astro-
Tech AT65EDQ
astrograph, Orion

7" Maksutov-Cassegrain

"When I first saw Jupiter through an old Meade 8" reflector, it was a seriously life-changing moment for me. I joined the US Navy after graduating from high school and was stationed in San Diego, California. Being on board a darkened ship in the middle of the Pacific Ocean is something everyone should experience - I witnessed the Milky Way being so bright that it was casting shadows!

"In 2009 I tried my hand at astrophotography. It was a steep learning curve and I went through a variety of different cameras."

The rugged lunar surface



Pillars of Creation, Eagle Nebula (Messier 16)

Steve Coates



Ocala, Florida
Telescope: Explore Scientific 127 APO
"It was after I bought my first telescope back in 2010 that

I began pursuing my hobby in astrophotography. Previously, I had never even looked through a telescope and had never really taken many photographs. I always enjoyed looking at images in astronomy magazines, as well as those taken by Hubble, and was keen to recreate something similar. I learned how to shoot and process my images of the night sky by scrolling through multiple websites for advice, as well as through much trial and error. At first I was pleased with my images of Solar System targets, but I quickly found myself photographing objects such as galaxies and nebulae with great success."

"I always enjoyed looking at images in astronomy magazines and was keen to recreate something similar"



Soul Nebula (IC 1871)



Monkey Head Nebula (NGC 2174)



Helix Nebula (NGC 7293)



Surface of the Sun

Mark Forbes



Stockport, UK
Telescope:
Altair Astro
Starwave 102
ED refractor
"Solar imaging is a recent area

of interest to me after seeing the spectacular images taken by astrophotographers using solar hydrogen-alpha filters. I was so keen to learn more about solar photography that I quite recently invested in a Daystar QUARK hydrogen-alpha filter for my telescope. Seeing so much detail on our own local star from my backyard is quite incredible."

Send your photos to...  @spaceanswers  space@spaceanswers.com



Visionary Telesto 1000/114

A good choice for observing a variety of night-sky targets, but also a great telescope for beginners on a budget

Telescope advice

Cost: £180/\$283

From: Optical Hardware Ltd

Type: Reflector

Aperture: 74.5"

Focal length: 39"

Best for...



Beginners



Low budgets



Planetary viewing



Lunar viewing



Double stars and bright deep-sky objects

A part of Optical Hardware's Visionary range, the Telesto was surprisingly easy to set up, even for a novice astronomer. When it comes to your very first telescope, we always recommend buying an instrument with an alt-azimuth mount rather than one that employs an equatorial mount. Equatorial mounts can be complicated to use and set up, and often give an extra bit of heft to the instrument, which can make transporting them quite difficult. We're pleased to note that the Telesto isn't heavy to carry and certainly isn't difficult to set up since the mount is quite basic. Its assembly is very intuitive and requires no tools to put together. Of course, given such a low price you shouldn't expect an instrument of high quality, and sadly the cheap aluminium tripod and flimsy red dot finder let the Telesto down. Combined with its low weight of just nine kilograms, we were also worried that a sudden gust of wind could blow the instrument over when we took it out to use on a particularly breezy November night. You do get a complete outfit for the price though, with everything you need to get started at touring the night sky, including two eyepieces and a Moon filter. And so, feeling hopeful, we put the Telesto to work.

Turning our attention to the North Star, Polaris, we realised that we had to tighten the locking screws to ensure that the telescope didn't move off target when we wanted to go 'hands-free' to look

through the eyepiece. But by

using the red dot finder, the

mount did the job when

we set about aligning the

telescope. The eyepieces - a

12mm and 20mm, giving

magnifications of 83x and 50x

respectively - were quite basic, but

given the general presentation of the telescope, we weren't surprised.

The telescope's tube is also compact

despite its 39" focal length, which

is due to a clever use of mirrors,

enabling the instrument to have

a shorter length and to make the

Telesto easy to carry around.

Popping the 20mm into the 1.25"

eyepiece holder, the accessory's fit was

snug but not so tight that we had trouble changing

eyepieces. This is good news, boasting versatility

on the instrument's part, and any additional accessories purchased at a later date are easily added to it. A half Moon was visible during our observations and we took advantage of its cratered surface. We received pleasing views of our rocky companion, taking in not just impact sites but also the lunar mare, which were defined even more using the supplied Moon filter. With no other Solar System targets - such as Jupiter and Saturn - within range of the telescope's optics at the time, we couldn't truly test the Telesto any further on its planetary viewing ability. However, given its view of the Moon, we believe that it is likely to provide decent sights of these objects too.

We next turned our attention to the brightest star in the sky, Sirius, which dazzled at magnitude -1.46 in the constellation Canis Major (the Greater Dog). Sadly we found that the star began to look distorted, with a fair degree of coma visible roughly 70 per cent out from the centre of the field of view. The inner 50 per cent of the field of view was very clear and sharp, while the portion at around 60 per cent provided passable views of Sirius. The Telesto was also capable of splitting double star Mizar, which can be found in the handle of the Big Dipper, into two components when to the naked eye it appears as one - a very good feature for double star enthusiasts.

Grabbing observations of the Pleiades, also known as M45, we detected a pleasing degree of nebulosity around the brighter members of this star cluster, which rests in the constellation of Taurus. This is the Merope Nebula, and a combination of the Telesto's optics and our adverted vision meant that the telescope passed the 'light-gathering test' to a pleasing standard. The nebulosity of the Orion Nebula, as well as the Trapezium Cluster found at its centre, was quite pleasing too.

Despite the setbacks in the telescope's optics and build, we couldn't really complain too much, as what was provided on the whole was very good for the price. Not only that but the Telesto allows users to view a variety of targets, including faint diffuse nebula, which require a telescope of good light-collecting capacity to be visible. We therefore recommend this telescope to beginners with a smaller budget.

Left: The red dot finder did the job, but has quite a flimsy build





"Views are sure to provide
a wow-factor for first-time
observers"



Right: The
Telesto's optics
were fair for
the price and
did the job
when it came
to observing a
variety
of targets

Far Right:
The equatorial
mount had to
be tightened
in order to stop
the telescope
from drifting





In the shops

The latest books, apps, software, tech and accessories for space and astronomy fans alike



Book **First on the Moon**

Cost: £25.00 / \$29.95 **From:** Sterling

The 50th anniversary of one of humankind's greatest achievements might have passed, but we couldn't put *First on the Moon* down. In honour of the groundbreaking Apollo 11 mission, this lavishly illustrated book - featuring stunning photographs and many rarely seen images and documents - tells the incredible story of the first men on the Moon.

Acclaimed science author Rod Pyle returns with a beautiful and insightful book commemorating Apollo 11. *First on the Moon* offers an exciting behind-the-scenes look at America's journey to the Moon - from the Space Race to the landing on the Sea of Tranquility to splashdown on Earth and the aftermath. Pyle spent years combing NASA archives and private collections for memorabilia from the mission, and the book includes everything from accessible explanations of the enormous challenges facing NASA to reproductions of original 1969 documents. It also features a number of specially commissioned photocompositions created from NASA Apollo images released in 2015. Many were parts of photomontages taken by the astronauts, and these compositions have now been carefully restored to their originally intended montage formats. With compelling firsthand accounts and a gripping narrative, this gorgeously designed volume fully immerses readers in the Space Age. The book includes a foreword by Buzz Aldrin and exclusive interviews with the adult children of the Apollo 11 astronauts.

Accessories **Fisher Space Pen**

Cost: £26.63 / \$27.00 **From:** Fisher Pens

Fisher's Bullet Space Pen is the perfect size to carry in your wallet, pocket, purse, car glove box, organiser or toolbox. When opened it's a full-sized, evenly balanced writing instrument. The original Bullet Space Pen was conceived in July of 1948. Paul Fisher was soon machining a new pen design shaped from solid aluminium. It became the first Fisher ball-point pen, the Bullet, and arguably the most popular writing instrument of the 20th century. This pen is now all brass with a chrome finish. Cited as an outstanding example of industrial art, the classic design of the Fisher Bullet Pen has been exhibited for years in the New York Museum of Modern Art. The Bullet's timeless styling has been the topic of many art books and magazine articles. Often imitated but never duplicated, the Fisher Bullet Space Pen continues to be a popular memento for space enthusiasts.





Kit Opticron Binoculars Adventurer T WP 10x50

Cost: £89.00 (approx. \$116.70) **From:** Opticron

It's often said that the best introduction to the night sky is through binoculars. They're lightweight, easy to use and generally inexpensive, much like Opticron's range of 'Adventurer' binoculars. Nice and compact, they fit snugly into your hands, and the rubber eyecups provide excellent eye relief.

The Moon and Jupiter offered some excellent viewing on which to test these 10x50 binoculars. Although we couldn't discern the bands on Jupiter, its Galilean moons were obvious, strung out either side like pearls. Meanwhile Earth's Moon was breathtaking with bright plains and darker mare, with the binocular's BAK4 prisms offering nicely contrasting views of its rugged, cratered surface.

We also tried hunting down some tougher targets. Although urban light pollution can hamper deep-sky observations, objects like double stars are perfect for binoculars. The constellation of Ursa Major (the Great Bear) offered the double stars Mizar and Alcor. Slight shaking of our hands made it impossible to split the two ice-blue stars. However, mounting the binoculars on a tripod to keep steady, we could distinguish the pair within our field of view.

"Nice and compact, they fit snugly into your hands, and the rubber eyecups provide excellent eye relief"

App SkyORB 2020.1.1

Cost: Free **From:** Google Play/iTunes

One of the best astronomy apps for Apple or Android phones is SkyORB. Downloading the free version - SkyORB Lite - onto our iPad, we were instantly struck by the quality three-dimensional rendering of the universe from planets and constellations to galaxies and nebulae. One really neat feature we found was the ability to zoom out from our Solar System, pulling back to look at a graphic of our own Milky Way galaxy. It takes a little while to get used to the icon menu that the app uses, but once you do you'll be able to use this app swiftly and efficiently. Its search function makes SkyORB a useful planetarium, its library of objects being well stocked, and it can depict what the night sky will look like at any time from any point - not just on Earth, but from other planets too. It was fun seeing what the night sky looked like from the point of view of the Curiosity rover on Mars, for example. A 12-month subscription can buy you access to the 'premium' version of the software, which is full-screen unlike the 'lite' version, provides access to greater details about astronomical targets and has more objects in its database.



Cecilia Payne-Gaposchkin

A remarkable astronomer who was fighting a constant battle against misogyny

At a time when our understanding of planets, stars and the entire universe was continuously shifting, Cecilia Payne-Gaposchkin made a discovery about the Sun that contradicted beliefs at the time: that the Sun was composed mostly of hydrogen and helium, and not the same in composition as the rocky Earth. However, this discovery – and much of her career progression – was downplayed. The only explanation as to why she suffered these setbacks was her gender.

Payne – which was her maiden name – was born on 10 May 1900 in Wendover, England. She was born into an upper-class family and was captivated by science from an early age. This passion eventually took her to the University of Cambridge to study physics and chemistry in 1919. It was here that she went from ‘following a passion’ to ‘captivated’ after listening to lectures from Nobel Prize winners and colossal names in science such as Ernest Rutherford, Arthur Eddington, Niels Bohr and J. J. Thomson.

After studying extensively in the fields of physics and astronomy, she still could not gain a degree, as this university did not officially start giving degrees to women until 1948. In the pursuit of an astronomy degree, Payne travelled to Harvard in the United States in 1923 with the invitation of Harlow Shapley.

By 1925, Payne had completed her PhD at Radcliffe College of Harvard, Cambridge, Massachusetts, under the tutelage of Shapley. Her thesis was a scientific masterpiece, but it was also met with much trepidation. Her work was centred around studying the composition and temperatures of stars, and it was this work that led her to claim that the Sun was made up of the simplest elements in the periodic table: hydrogen and helium. As mentioned earlier, this went against the understanding at the time, and was completely discredited by leading astronomer Henry Norris Russell. Russell said it was simply impossible and told Payne not to make this claim in her thesis.

It is common knowledge now that the Sun is 98 per cent hydrogen and helium, and in fact, these elements also make up 74 per cent of the observable matter in the universe. Russell later



She became the first woman to head a department at Harvard

© Getty

“The only explanation as to why she suffered setbacks was her gender”

came around to Payne’s way of thinking in 1929, after he had conducted his own work which showed Payne to be correct.

Payne stayed with Harvard Observatory, where she worked as a full-time astronomer. Rather frustratingly, she would not gain an academic position due to the misogynistic beliefs of Harvard president Abbott Lowell. Despite her being grossly overqualified, it took until 1956 for her to become the first-ever woman to reach the position of full professor and chair of the department of astronomy.

Payne-Gaposchkin passed away on 7 December 1979, having remained in Cambridge. It is unquestionable that Payne-Gaposchkin’s efforts have been extremely influential in the field of astronomy and in our understanding of the wider cosmos. Yet her struggles and determination made her become what she described as a ‘rebel against the feminine role’.

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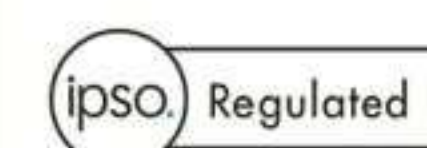


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APOLLO 11

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When astronauts began to explore the reaches of outer space, Paul Fisher realized that there was no existing pen which could perform in its freezing cold, boiling hot vacuum. Countless experiments and a common-sense approach resulted in the invention of the sealed and pressurized ink cartridge and in 1967, after 18 months of rigorous testing by NASA, the Fisher Space Pen® was selected for use by the astronauts. It is still used today on all manned space flights.

Matte Black Bullet Space Pen
Moonscape Box



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REVIEWED IN
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